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# AMERICAN AIR NAVIGATOR

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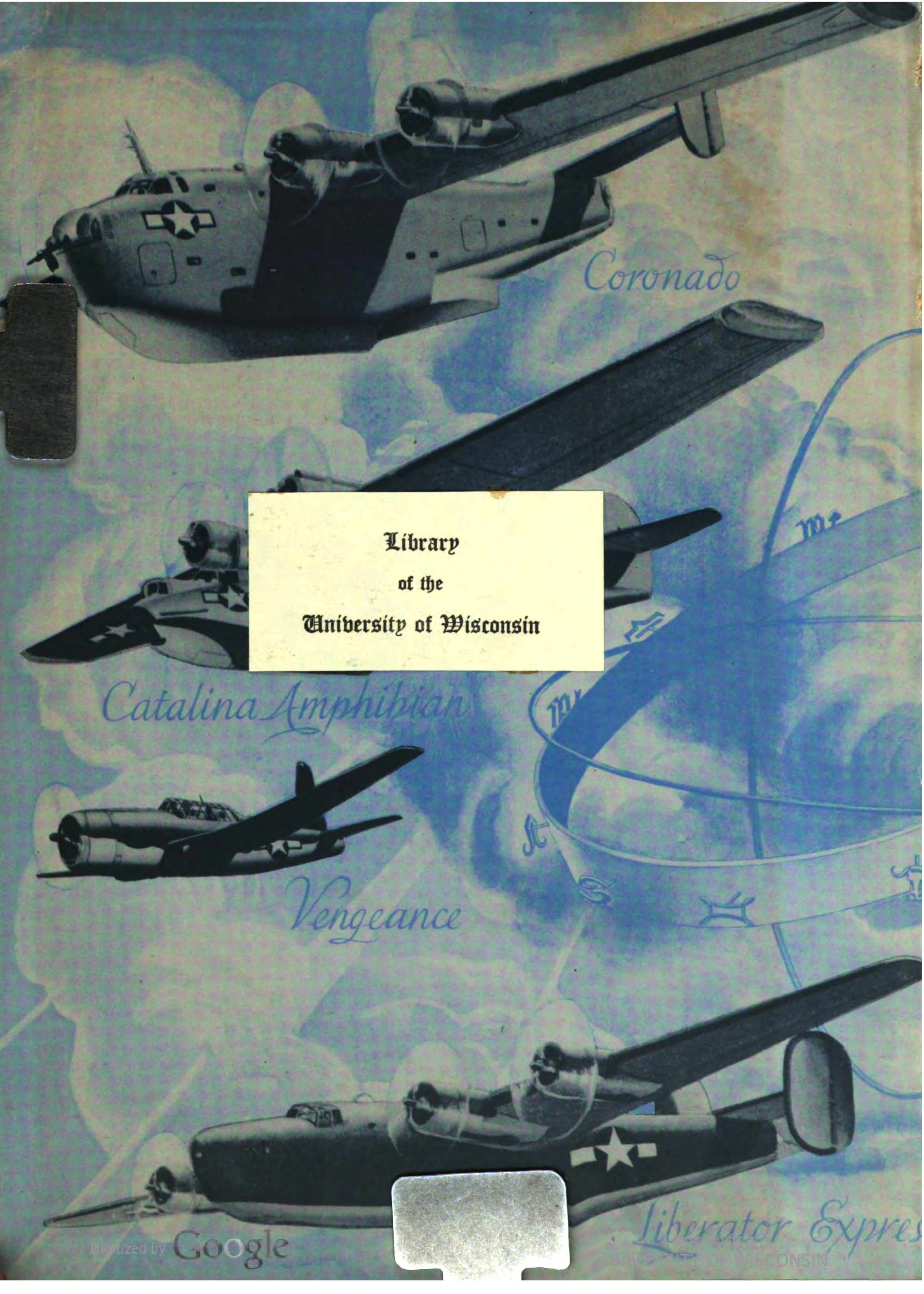


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## ERRATA

Page 60—after "for range reception . . . ," add "in conjunction with homing using left-right indicator . . . ."

Page 136—Problem Work No. 29—Date: "May 1, 1943."

Page 220—Problem Work No. 10—Answer No. 13 = 183°/41
D. R. REVIEW No. 1—Answer No. 6(a) TAS = 188 knots; Answer No. 6(b) = 191 knots. TAS.

Page 221—Problem Work No. 14—Answer No. 4 = 52°; Answer No. 16 = 150°.

Page 223—Problem Work No. 23—Answer No. 19, LHA = 122°E.

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# AMERICAN AIR NAVIGATOR

*By*

CHARLES MATTINGLY

*Chief Navigator*

*Consolidated Vultee Aircraft Corporation*

*Published by*

CONSOLIDATED VULTEE AIRCRAFT CORPORATION

SAN DIEGO, CALIFORNIA

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The American Air Navigator is published by Consolidated Vultee Aircraft Corporation as a token of the organization's faith in the brilliant future of global transportation.

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# PREFACE

"American Air Navigator" is intended primarily for the serious student of aerial navigation, and for those actually engaged in this interesting and vital profession. This book attempts to present air navigation as it really is today; it is strictly a training text for instructional purposes, and a reference source for professional navigators.

During twelve years of actual experience as a navigator, both surface and aerial, I have attempted to read carefully every book published on the subject of navigation and, in more recent years, books on aerial navigation. One characteristic seems common to most of them—an over-emphasis of the theoretical. Obviously, there is need for thorough coverage of theory, and many of these texts cover the subject as comprehensively as present limited knowledge of this science allows.

Acting on the conviction that there is need for a book which separates practical, applicable information from the vast field of theory, and which presents such information in compact form, I have attempted to collect into this volume all the data essential to successful aerial navigation as we know it today.

The fact that the book is laid out in outline form is no coincidence. Rather, it is the writer's belief that its outline form will make the volume an easy, intelligible teaching aid, and will permit rapid reference.

Appreciation is due here to the many navigators, both surface and aerial, who have assisted me in the compilation of this book. Special credit must be given Peter Selby, without whose help and encouragement this volume might never have reached publication. Likewise, David Hellyer gave valuable assistance in editing and correlating material in the book. For the high quality of the illustrations, thanks are due the Consolidated Vultee (San Diego Division) Service Illustration Section, under the direction of Charles Bundo, Jr.

C. D. M.

June 1, 1944
San Diego

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# INTRODUCTION

Half a dozen years ago, the professional aerial navigator was a newcomer to the aviation industry, and virtually unknown to the public. Non-stop flights across vast stretches of ocean still were regarded with awe, and few indeed had experienced the thrill of an aerial journey to Australia, India or London.

In 1940, Richard Archbold, renowned explorer and adventurer, accomplished one of the first extended, over-water flights "without incident" in a Consolidated Aircraft Corporation airplane, the PBY "GUBA." The flight of the Guba marked a milestone in the history of aerial navigation, and helped to blaze a trail which today is followed by hundreds of giant aircraft each month.

Pioneering with Archbold in this epic adventure were veteran pilot Russell Rogers, now director of Flight and Service for Consolidated Vultee Aircraft Corporation, and S. J. Barinka, superintendent of field operations for Convair at San Diego, who acted as the Guba's flight engineer. The experience these men gained on this pioneer flight, and on scores of later trips, helps make Consolidated Vultee's flight department today outstanding in the industry.

Forced by the second World War to regard the entire globe as a flying field, aviation today considers trans-oceanic flights little more than commonplace. At this moment, no spot on earth is more than 60 hours removed from your front door—thanks to aviation—and this "time-distance" rapidly is diminishing as the industry produces faster, longer-ranged aircraft.

So, just as yesterday he was a newcomer, today the aerial navigator is symbolic of the history-making strides taken by aviation since Pearl Harbor. His importance in the stirring drama of aviation stresses the fact that global air transportation is today a reality, where only yesterday it was a fond hope and dream.

In the "American Air Navigator," Charles Mattingly, Chief Navigator for Consolidated Vultee Aircraft Corporation, has recorded much of the valuable information and experience gained during his 12 years of navigating. Hundreds of Consolidated Vultee pilots, copilots, navigators, radiomen, and engineers have received instruction in aerial navigation under Mattingly's able tutelage, and the enviable safety record of Consolidated Vultee's over-water air transportation bears witness to the accuracy and thoroughness of this instruction.

Though "American Air Navigator" is published primarily as a textbook for training the corporation's flight personnel, it is fitting that Consolidated Vultee, as a leader and pioneer in the field of global transportation, should make this vital information available to all, in the interests of advancing world-wide air travel.

TOM M. GIRDLER,
Chairman of the Board,
Consolidated Vultee Aircraft Corporation,
San Diego, California.

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# ☆ 1 ☆

# EARTH AND CHARTS

AN INTIMATE, working knowledge of the earth's shape, size and geography is as essential to the well-informed aerial navigator as is a knowledge of aerodynamics to the successful pilot. It is not enough that the navigator know that the earth is round. He must understand what this spherical shape means in terms of his job; he must realize that the earth's very shape gives rise to many navigational problems which it will be his duty to solve.

The navigator must think of the entire earth as his workshop. In fact, the whole universe is his laboratory, for he must employ the stars and planets themselves in his daily work. No other calling in the aviation industry—and few in any industry—requires thinking and working in such universal concepts!

From the start, then, the navigator must prepare himself to learn a new language. He must break away from habits of thinking which have taught him to regard a neighboring city as "distant," for his work soon may make a 10,000-mile flight appear commonplace.

Realizing the necessity of thinking in global concepts, the navigator should study the following information earnestly and sincerely. If he adopts such an approach, he will find mere definitions will become living phrases to be added to his new vocabulary. A working familiarity with these terms, and a thorough understanding of their meaning, might some day mean the difference between life and death.



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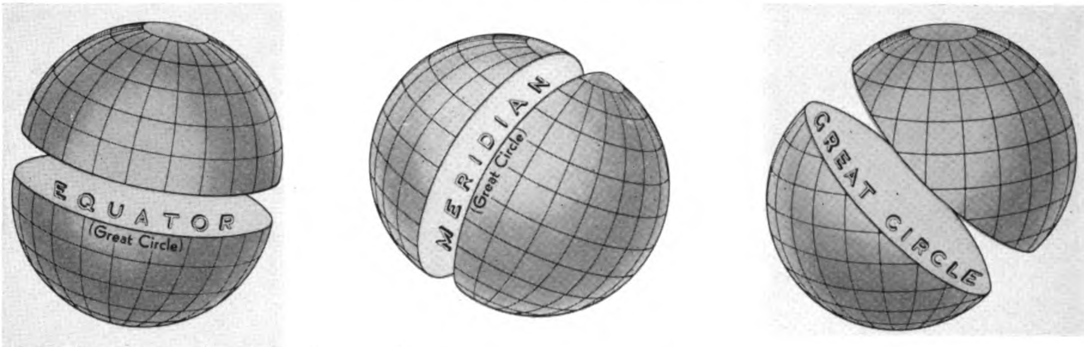


FIG. 1—GREAT CIRCLES

## THE EARTH

**Shape**—The earth is an oblate spheroid; that is, a sphere slightly flattened at the poles. The polar diameter is about twenty-seven (27) miles less than the diameter at the equator. However, for purposes of navigation, the earth may be regarded as a sphere.

**Size:**

Polar diameter ....................7,900 miles
Diameter at equator............7,927 miles

### TERMS

**A Sphere** is a body bounded by a surface, all points of which are equidistant from a point within, called the center.

**A Great Circle** is an imaginary circle on the earth's surface, the plane of which passes through the center of the earth. (Figure 1)

**A Small Circle** is an imaginary circle on the earth's surface, the plane of which does *not* pass through the center of the earth. (Figure 2)

**Meridians** are great circles passing through the earth's poles. (Figure 3)

**The Prime Meridian** is the meridian used as reference line for the measurement of longitude. Known also as the Greenwich meridian because it passes through the Naval Observatory at Greenwich, England, it was selected arbitrarily as a reference line and is so employed by navigators of most countries of the world. (Figure 3)

**Longitude** is angular distance East or West of the prime meridian, measured in degrees of arc from 0°-180°. (Figure 3)

**The Equator** is a great circle on the earth's surface lying midway between the poles. It is used as the prime reference line for the measurement of latitude. (Figure 4)

**Parallels of Latitude** are divisions of latitude parallel to the equator. They are small circles on the earth's surface. (Figure 4)

**Latitude** is angular distance North and South of the equator measured in degrees of arc from 0°-90°. (Figure 4)

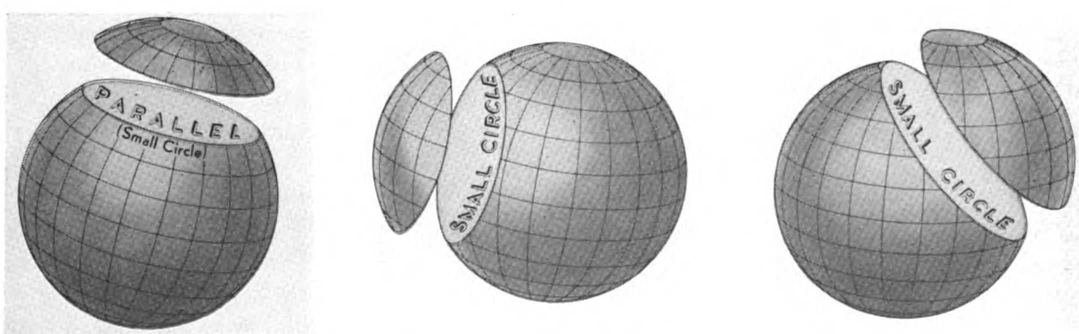


FIG. 2—SMALL CIRCLES



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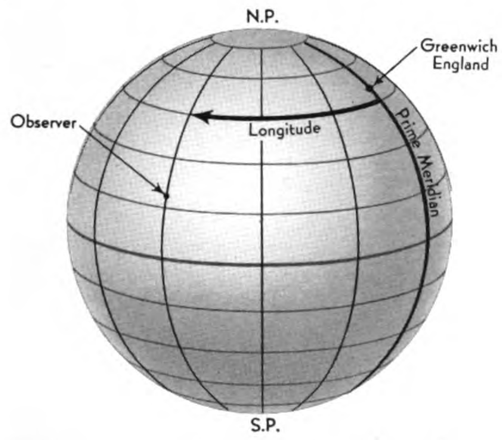


FIG. 3—MERIDIANS, PRIME MERIDIAN AND LONGITUDE

**A Statute Mile** is a unit of distance equal to five thousand, two hundred and eighty (5,280) feet, and is used only in over-land flying.

**A Nautical Mile** is a unit of distance equal to six thousand, eighty (6,080) feet, and is used in *all ocean flying.*

**A Knot** is a unit of speed and is equal to one nautical mile per hour.

**A Great Circle Track** is the path made good over the ground when flying a great circle course. It is the shortest distance between any two places on the earth's surface. (Figure 5)

Due to the convergence of the meridians toward the poles, the great circle track between two places will cross each meridian at a different angle, except at the equator or when the track coincides with a meridian.

**A Rhumb Line** is a line (or course) which intersects all meridians at the same angle. (Figure 5) Because it appears as a straight line on a Mercator chart (Figure 6) it is the course line most used in ocean aerial navigation. Actually, on the surface of the earth, it is a curved line which is sometimes known as a loxodromic curve, or equiangular spiral. On the equator, or along a meridian, the rhumb line coincides with the great circle track.

## CHARTS

**A Chart,** or a map, is a graphic representation of a portion of the earth's surface laid out upon a plane surface.

When man first began to draw maps, the world he knew was very small indeed. His ideas about the world around him, like the maps he drew, were crude and incomplete.

At first his map-making experiments were, in all probability, attempts to satisfy a natural curiosity about his surroundings. In time, however, maps became vital necessities. Caravans to the East used them for guidance through strange lands. Ship captains felt more secure in navigating from port to port if the best available maps were aboard.

Then, as mariners gained more courage, and ventured farther and farther from sight of land, the need arose for a new type of map, a

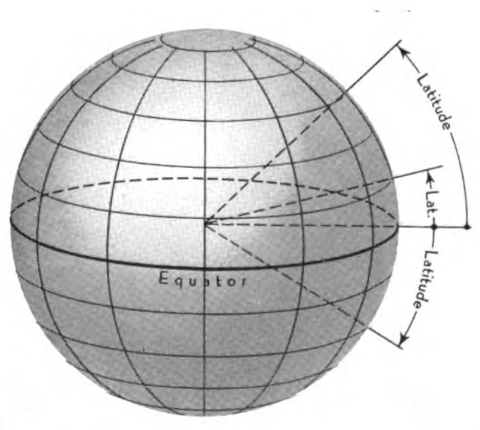


FIG. 4—EQUATOR, LATITUDE AND PARALLELS OF LATITUDE

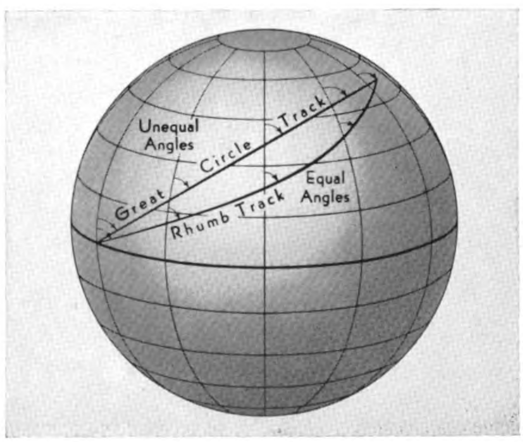


FIG. 5—GREAT CIRCLE AND RHUMB TRACK ON EARTH'S SURFACE



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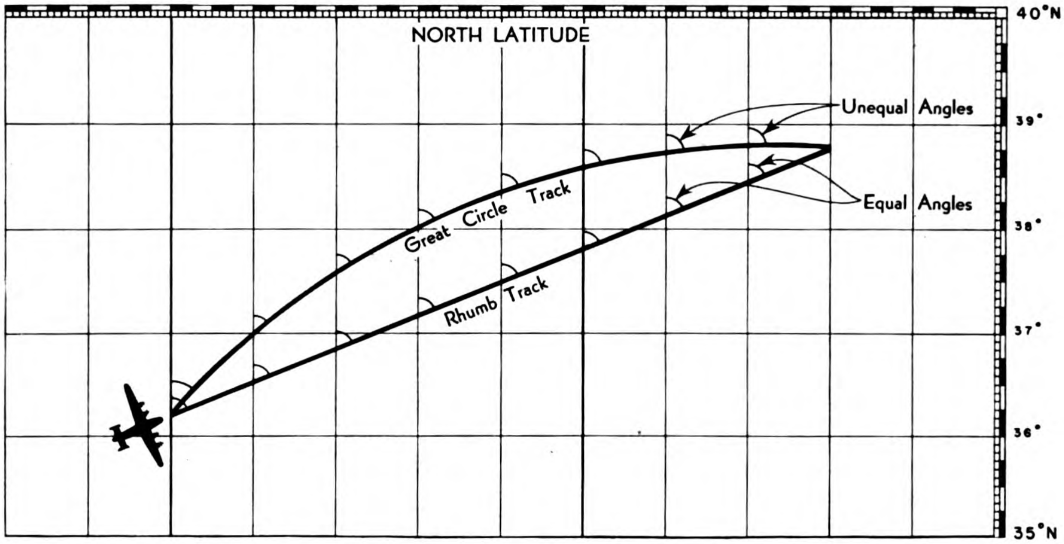
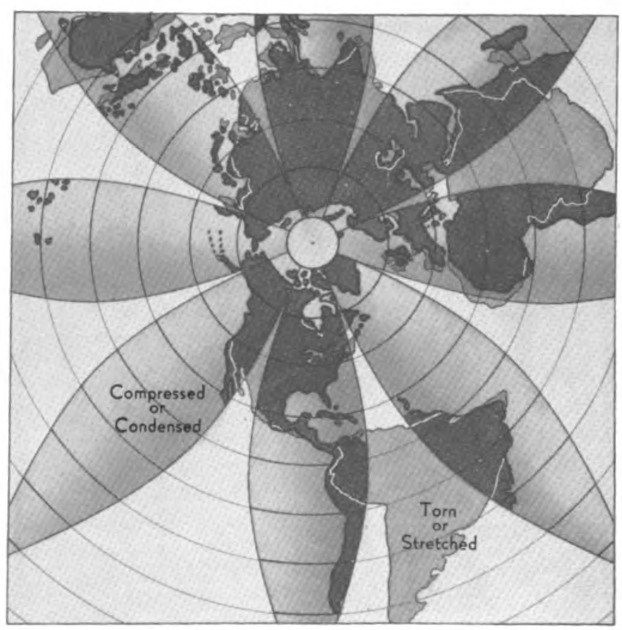



FIG. 6—GREAT CIRCLE AND RHUMB TRACK ON MERCATOR CHART

map which would represent large areas of water and adjacent or included land in some graphic manner. These maps, which dealt primarily with water areas, came to be known as charts.

Thus arose the distinction between maps and charts: a map is primarily concerned with the land, while a chart supplies information mostly about water and land bounded by water. This distinction makes the chart especially valuable to the navigator, for whom—in fact—the chart was designed.

Sphere




Sphere Distorted into Plane

FIGS. 7-8
SURFACE FEATURES OF EARTH
DISTORTED ON PLANE SURFACE



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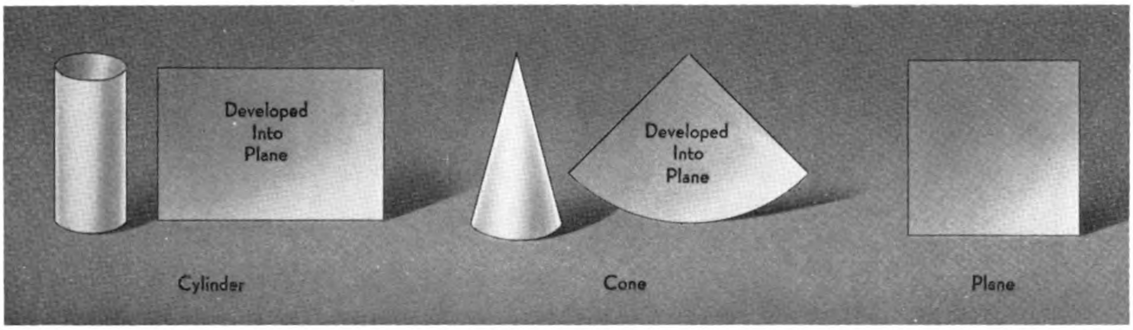


FIG. 9 FIG. 10 FIG. 11

## DEVELOPMENT OF CHARTS

**The Ideal Chart** would be one which represented graphically the entire surface of the earth, exactly to scale, on a flat sheet of paper. However, the earth's surface bounds a sphere (Figure 7) which cannot be developed upon a plane surface for the same reason that a section of orange peel cannot be made to lie flat unless it is torn, stretched, or compressed (Figure 8). Therefore, a system of map making has been devised which permits the surface features of the earth to be projected upon surfaces capable of development into a plane.

**Three Surfaces** which may be developed into a plane surface are:

Cylinder (Figure 9)
Cone (Figure 10)
Plane (Figure 11)

**Chart Projections**—Charts are transferred to developable surfaces by a method known as "projection." By projection is meant to project, from the center of the earth (theoretically) the surface features of the area to be charted upon a developable surface held tangent (touching) or nearly tangent to the earth's surface. Actually, the chart is made by mathematical computation. The principle of the projection may best be illustrated, however, by imagining the eye of the observer at the center of the earth.

A certain amount of distortion of surface features will remain even when charts are made by projection. Each of the three developable surfaces will produce a chart with varying degrees of distortion. For this reason, many different types of projection have been devised, each intended to meet a specific need by embodying certain desirable characteristics while eliminating, so far as possible, characteristics which are less desirable.

**The Four Principal Projections** most commonly used by the aerial navigator are:

Mercator
Lambert
Gnomonic
Polyconic

## MERCATOR CHART

**Importance** — Because its particular features make it best suited for ocean flying, the Mercator chart is the most important chart used in ocean navigation.

**Description**—The Mercator chart principle involves depicting surface features of the earth as they would appear if projected onto a cylinder held tangent to the earth at the equator (Figure 12). It is not a true geometric projection, however, since the projection point (eye) is considered to move along the earth's axis toward the poles in order that the distances between parallels of latitude will increase in the same proportion as the distances between meridians at the same latitude (Figure 13). Thus, the surface features of the earth when projected on the cylinder retain their shape, although they become proportionately larger as the latitude increases. The actual magnifying factor is equal to the secant of the latitude (a mathematical equation).

**Desirable Features** — The desirable features of the Mercator projection arise primarily from the fact that all meridians of longitude and parallels of latitude are represented as parallel straight lines, perpendicular to each other. As a result, positions are easily plotted on it, courses and bearings are straight lines easily measured, and charts of the same scale



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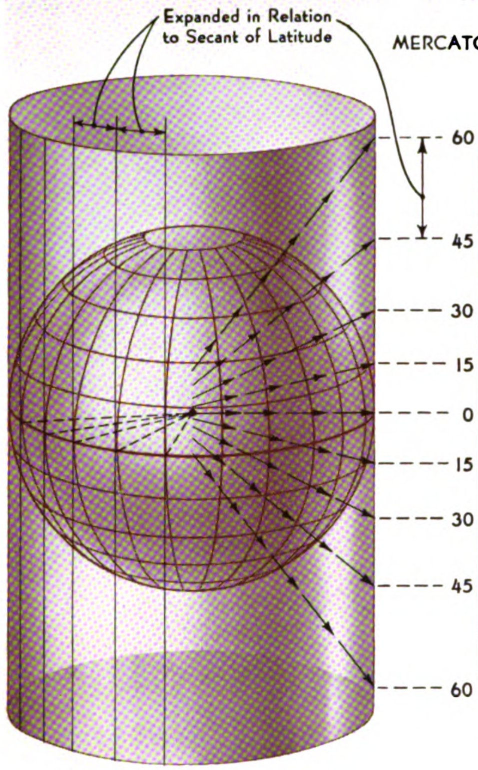


FIG. 12 Projection

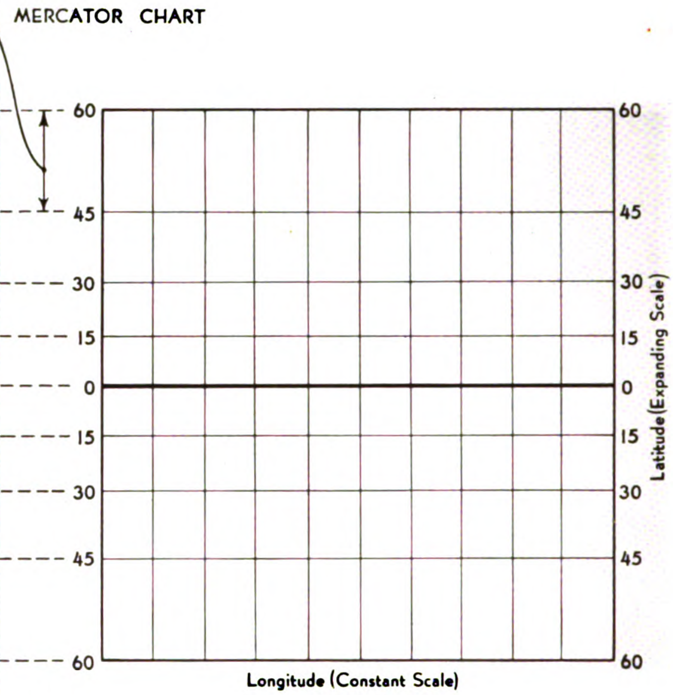


FIG. 13 Development

may be joined together accurately. Other advantages are a distance scale in nautical miles, simplicity of graphic construction, and the important fact that a rhumb line appears as a straight line (Figure 14).

**Undesirable Features**—Perhaps the least desirable feature of this projection is the expanding latitude, which results in a non-uniform distance scale as well as in great distortion in high latitudes. Undesirable also is the fact that a great circle track—actually the shortest distance between two points—appears as a curved line, hence radio bearings must be converted to Mercator bearings (rhumb lines) for plotting.

**Measuring Distances** — Since one minute of latitude equals one nautical mile, the latitude scale (Figure 14) is used to measure distance. However, due to the fact that latitude expands, it is necessary to *measure distance at the mid-latitude of the track being measured.* (Figure 14)

**Graphic Construction** — This method of construction, by which the navigator may make his own chart, does not result in an exactly correct Mercator chart, although it is sufficiently accurate for obtaining a fix or plotting a position if the North and South extent is limited to 6° and latitude does not exceed 60°.

These limitations are, however, of a very general nature. Actually, for purposes of air navigation, sufficient accuracy can be obtained even when much greater extents of latitude are employed. The nearer the area to be covered by the chart is to the equator, the less distortion exists, hence the greater the area that can be included while retaining reasonable accuracy.

Graphic construction is a quick and easy method of making a chart, and charts so constructed may be used throughout the remainder of this book wherever needed. The reader is especially urged to utilize this method of construction to develop charts which he will need in connection with the problem work. Charts so constructed also can be used for actual navigation in the event the navigator should



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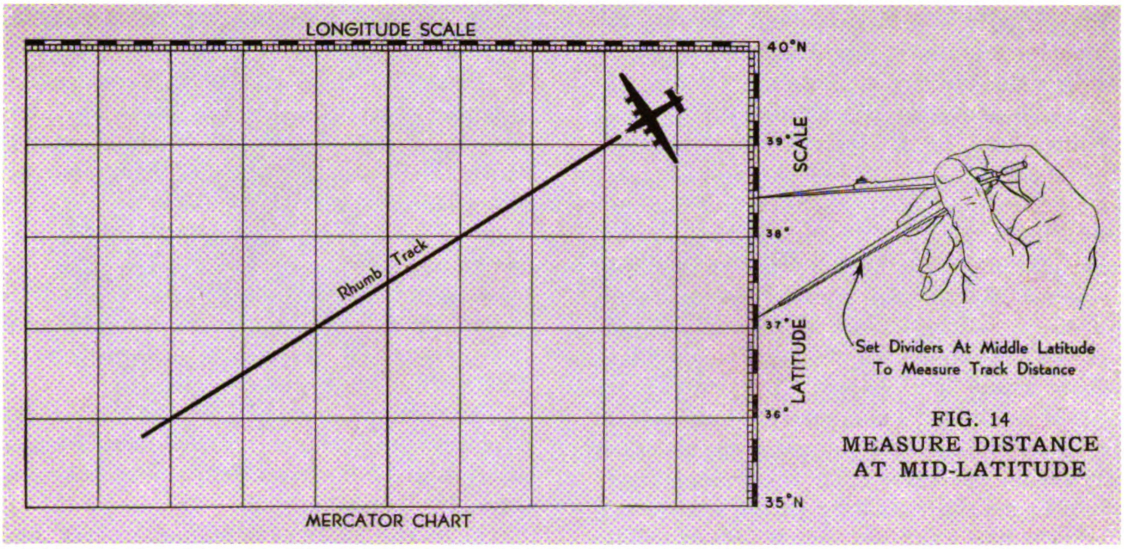


FIG. 14
MEASURE DISTANCE AT MID-LATITUDE

find himself without the proper plotting chart.

*Example:* It is desired to plot a fix which is approximately 25° North latitude, and 170° West longitude. (Refer to Figure 15)

a. Draw a horizontal line near lower edge of paper.

b. Erect a perpendicular to this line near left edge of paper.

c. At the point of intersection of these two lines, draw a line making an angle of 25° with the horizontal line.

d. Using any convenient scale, set the dividers equal to 60 units (each a "minute") and mark off 60-unit intervals on the sloping line, and also on the perpendicular.

e. Through these points draw lines parallel to the horizontal and perpendicular lines, and number them for latitude and longitude as per problem, making the mid-latitude 25° and the mid-longitude 170°.

f. Through the use of the 60-unit latitude scale, the latitude of any position on the chart may be quickly found, and distances easily measured. By setting the zero and 60-unit points of the reference scale to coincide with the meridians on either side of the point

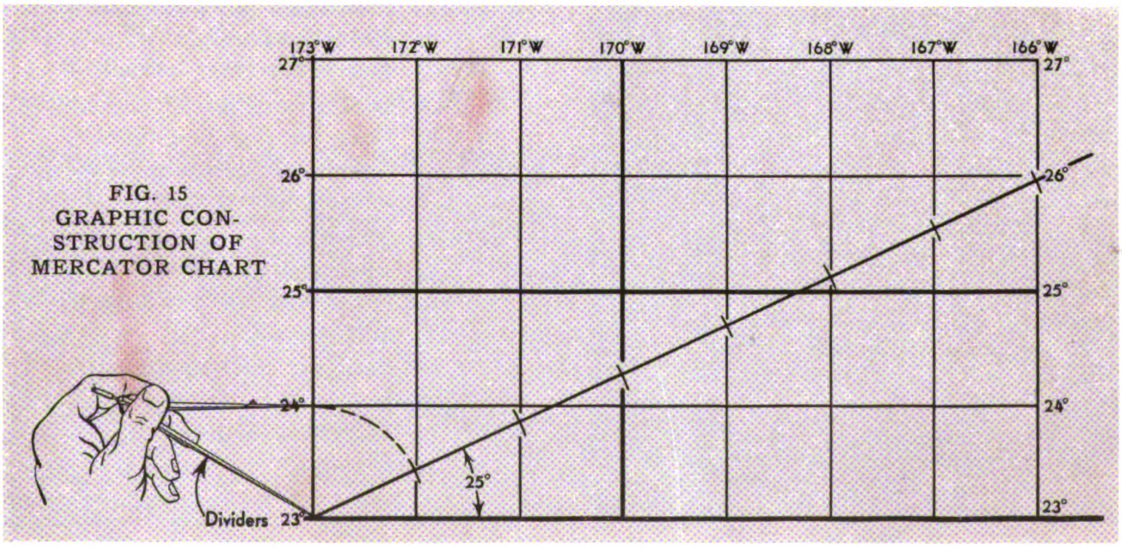


FIG. 15
GRAPHIC CONSTRUCTION OF MERCATOR CHART



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whose longitude is desired, and aligning the scale edge to pass through the point, longitude can be read directly off the scale. (Figure 15)

**Construction by Meridional Parts**—Since the meridians on a Mercator chart are parallel, it can be shown that the longitude must have been expanded by the secant of the latitude. Hence, in order for the projection to remain conformal, the latitude must be expanded similarly. Therefore, in constructing an accurate Mercator chart, each minute of latitude has to be multiplied by the secant of the latitude at which it is located. But a minute of latitude is equal to a minute of longitude at the equator, and since the longitude does not vary on the Mercator chart, it is customary to establish the chart scale by letting a minute of longitude equal any convenient unit of length. The length of any minute of latitude then will be equal to the length of a minute of longitude multiplied by the secant of the latitude. Thus the length of a minute of latitude at 30° North is equal to a length of a minute of longitude times the secant of 30°. As an illustration, if 1′ longitude = 1/16 inch, then 1′ latitude at 30° N (or S) = 1/16 inch x secant 30°.

These expanded minutes of latitude, from the equator to the poles, are known as meridional parts, and the table of meridional parts (Table No. 5, Bowditch*) gives the sum of the meridional parts from zero, at the equator, to the desired latitude.

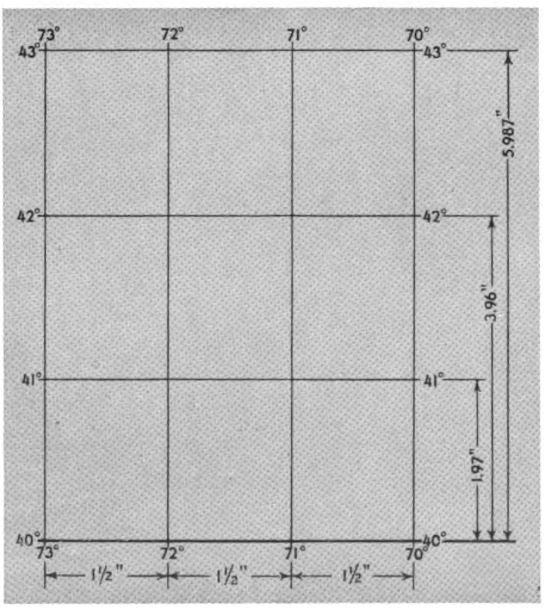


**FIG. 16**

*Example:* It is desired to construct a Mercator chart based on the following information: latitude 40° to 43° North, longitude 70° to 73° West, scale 1½ inch equals one degree of longitude at the equator, or 1/40 inch equals one minute of longitude at equator. (Refer to Figure 16)

a. Draw parallel North and South lines 1½ inch apart. Number these lines even degrees of longitude: 70°, 71°, 72°, 73° from East to West. These are the meridians.

b. Near the lower edge of the work sheet, erect a perpendicular to the meridians. Assume this line to be the principal parallel and number it 40° North latitude.

c. In the table of meridional parts, find meridional parts of principal parallel and all other parallels of latitude.

d. Compute separately the lengths of the meridians between each parallel of latitude and the principal parallel by multiplying the difference of meridional parts by the scale unit representing one minute of longitude:

| | |
|---|---|
| **2607.6** | **Meridional parts latitude 40° (principal parallel)** |
| **2686.2** | **Meridional parts latitude 41°** |
| **78.6** | **Difference of meridional parts** |
| **x 1/40″** | **Scale for 1′ of longitude** |
| **1.97″** | **Length of meridian between latitude 40° and 41°** |
| **2607.6** | **Meridional parts latitude 40° (principal parallel)** |
| **2766.0** | **Meridional parts latitude 42°** |
| **158.4** | **Difference of meridional parts** |
| **x 1/40″** | **Scale for 1′ of longitude** |
| **3.96″** | **Length of meridian between latitude 40° and 42°** |
| **2607.6** | **Meridional parts latitude 40° (principal parallel)** |
| **2847.1** | **Meridional parts latitude 43°** |
| **239.5** | **Difference of meridional parts** |
| **x 1/40″** | **Scale for 1′ of longitude** |
| **5.987″** | **Length of meridian between latitude 40° and 43°** |

*BOWDITCH, or Hydrographic Office Publication No. 9. Originally published by Nathaniel Bowditch in 1802, the volume is regarded as the "Bible" of surface navigation by most ocean navigators.



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LAMBERT CHART

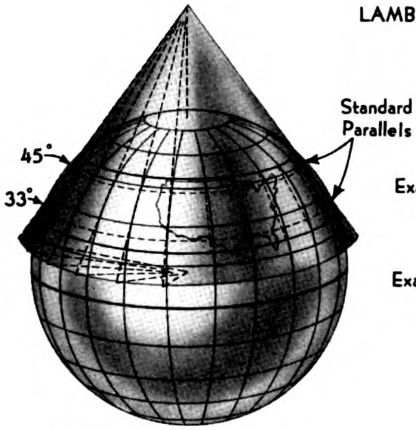


FIG. 17 Projection

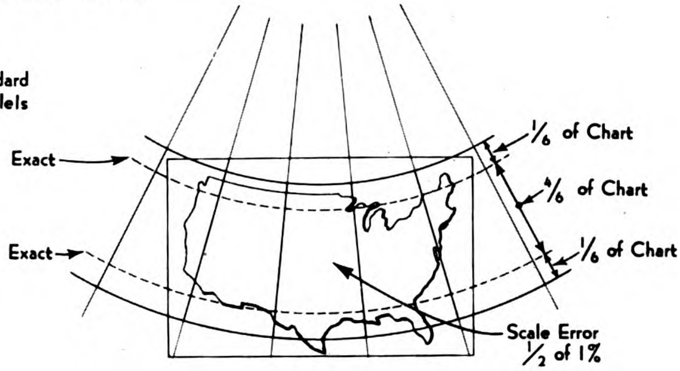


FIG. 18 Development

e. From principal latitude 40° measure off the computed meridian lengths (1.97″; 3.96″; 5.987″), and through these points draw lines parallel to the principal latitude 40°. Number these toward the pole 41°, 42°, 43° respectively.

**Note:** Minutes of longitude are found by dividing the degrees into 60 equal parts. Minutes of latitude must be computed from the principal parallel, the same as degrees, if extreme accuracy is desired.

## LAMBERT CHART

**Description**—In the Lambert chart, the surface features of the earth are projected upon a right circular cone which is made to intersect the earth's surface at two parallels of latitude, called standard parallels of the chart (Figure 17). Along the standard parallels the scale is exact, but between them there is a slight distortion due to compressing or condensing of the features (Figure 18) and beyond them expansion or stretching of features occurs. Hence, in order to maintain as nearly as possible the same limits of error throughout the chart, the standard parallels are so chosen that one-sixth of the area to be projected is above, and one-sixth below, these parallels.

This chart was developed by Lambert in 1772, but it was not until the first World War that its possibilities were fully realized. At that time, the Allies used it for military maps because it afforded a maximum of accuracy in measuring directions and distances where the difference of latitude was not too great. Because of the accuracy with which it portrays topographical features, and because of the fact that, for all practical purposes, radio bearings may be drawn as straight lines, the Lambert

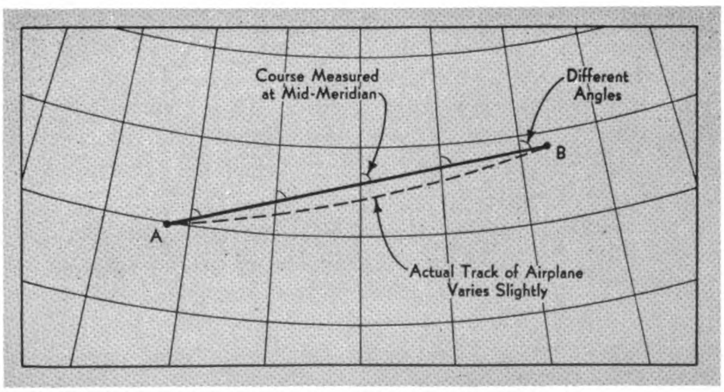


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FIG. 19—MEASURING COURSE ON LAMBERT CHART

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GNOMONIC CHART

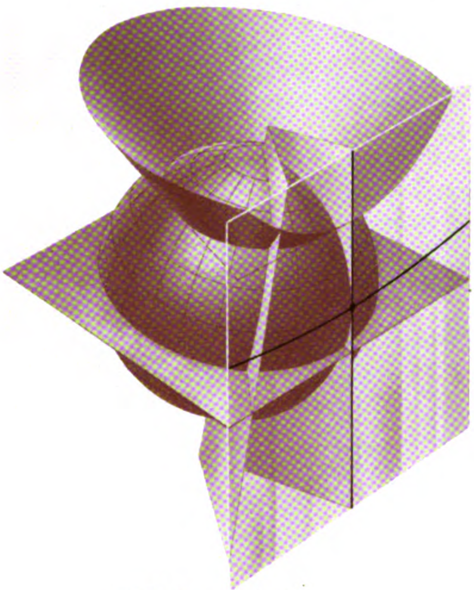

FIG. 20 Projection

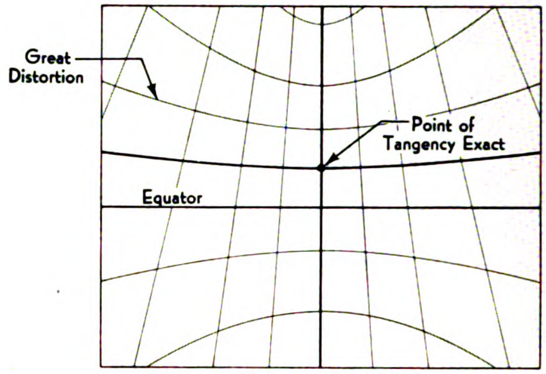


FIG. 21 Development

projection was selected by the Coast and Geodetic Survey for the development of aeronautical charts of the United States and Alaska.

**Desirable Features**—The scale is so nearly exact that distances may be measured directly, as though the scale were constant. A straight line very closely approximates a great circle, hence it may be considered the shortest route. This latter fact makes the chart extremely useful for radio navigation, as it is possible to plot radio bearings directly. Another advantage is that any number of charts may be joined together in any direction with perfect junctions.

**Undesirable Features**—Since on this projection the meridians converge, a straight course line will cross each meridian at a different angle (Figure 19). However, instead of flying a constantly changing course in order to follow a direct line, the practice generally is to measure the course at the mid-meridian. Though this method of measurement causes the actual track of the aircraft to differ slightly from the course plotted, it enables the pilot to hold a constant heading (Figure 19).

Plotting of position also is more difficult on this type of projection because the meridians and parallels of latitude are not shown as parallel straight lines as on the Mercator projection.

## GNOMONIC CHART

**Description**—The gnomonic chart is developed by projecting a portion of the earth's surface onto a plane held tangent to the earth at a point (Figure 20). At this point of tangency, the surface features will be exact, but distortion is great in all directions away from this point (Figure 21).

**Desirable Features**—This chart was developed primarily in order to show true great circle tracks as straight lines. Its principal use is in measuring the shortest distance between two points and in providing a graphic method of plotting the great circle track. The great circle track, drawn as a straight line on the gnomonic chart, is divided up into a series of chords, and the coordinates of these chords may then be re-plotted upon the Mercator chart for actual navigation.

**Undesirable Features**—Great distortion of the surface features in all areas except at the one point of tangency, and great difficulty in plotting positions because of a non-uniform scale are the principal drawbacks to this type of chart.



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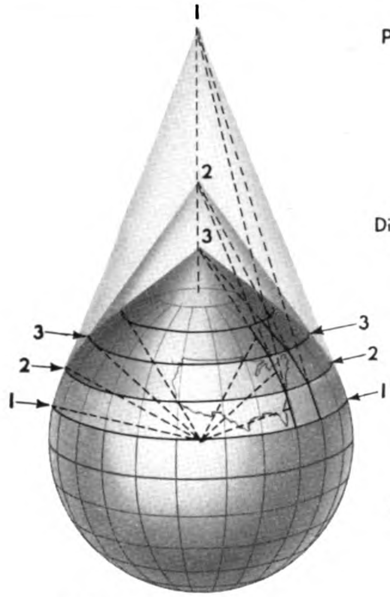


FIG. 22 Projection

POLYCONIC CHART

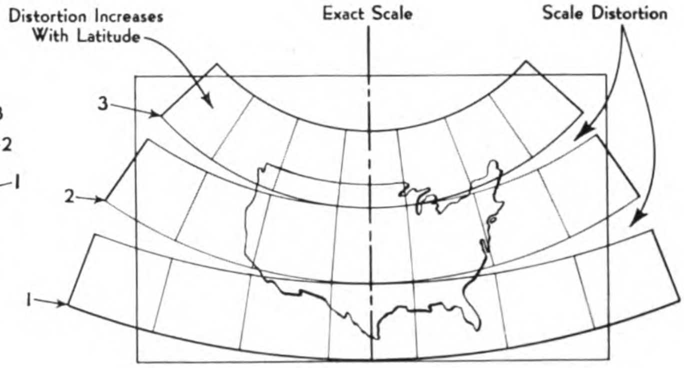


FIG. 23 Development

## POLYCONIC CHART

**Description**—The polyconic chart derives its name from its method of development, which involves projecting from the center of the earth a portion of the surface features onto a series of cones, each tangent to the earth's surface at a different parallel of latitude, but having a common axis (Figure 22). This chart (Figure 23) is useful for small areas where accuracy of topographical features is most important, since it incorporates even less distortion error than the Lambert chart.

**Desirable Features** — The scale being almost exact near the central meridian, even for large North and South areas, it is a highly desirable projection for pilotage charts, such as harbor and small coast line charts. It is used also by U. S. Army Engineers for fire control and tactical maps.

**Undesirable Features**—Use of the chart for practical navigation is limited to small areas for several reasons. The type of distortion inherent in this projection limits its use to charts of wide latitude and narrow longitude. On larger charts, positions are difficult to plot and courses are hard to measure because the meridians are curved and the parallels of latitude do not intersect them at right angles.

## PROBLEM WORK

No. 1 Make drawings showing principle of the Mercator, Lambert, and gnomonic projections. List desirable and undesirable features of each.

No. 2 Construct graphically a Mercator chart for an area extending 2° North and South of latitude 25° N., and 2° East and West of longitude 127° W.



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# INSTRUMENTS

JUST as the entire globe is the aerial navigator's workshop, so his aircraft's navigational instruments are his most important tools. Those to be discussed in this chapter are the instruments actually employed by the long-range navigator for extended, over-water flights. Included are:

- Compass
- Altimeter
- Airspeed Indicator
- Thermometer
- Chronometer
- Drift Meter

Not included in this chapter are discussions of the radio compass and the aircraft octant. Each of these is sufficiently important to merit detailed treatment in later chapters.

No attempt is made to describe the construction of instruments discussed in this chapter except where such descriptions are vital to an understanding of their actual use. Detailed mechanical descriptions are, for the most part, left to manufacturers' manuals, which are available to those interested in the construction and servicing of these units. Furthermore, all aircraft instruments are subject to such change that any text which attempted to describe them in detail might well be rendered obsolete overnight.



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The stress in both text and illustrations, therefore, is laid on principle and use of these navigational "tools," rather than on their physical make-up.

## COMPASS

**Description** — Both functionally and historically, the compass is first and foremost among all navigational instruments. Briefly, the compass is an instrument which points in a constant direction regardless of the aircraft's movements, and from which, by reference to a graduated card, the aircraft's direction of flight may be determined. The earliest-type compass probably was discovered when ancient navigators learned that a piece of lodestone or a magnetic needle, when floated on a cork in a bowl of water, would point in a constant direction, thus enabling them to navigate their sailing ships without reference to landmarks. Refinements on this early compass were made through the centuries, and the process of refinement continues today.

In recent years several other scientific principles have been utilized in attempts to develop a compass which would be even more reliable and constant than the magnetic compass. Among principles utilized are those of the gyro, and the movements of celestial bodies.

1. **Gyro Compass**—The gyro compass has proved highly successful aboard surface ships, but so far no model light and rugged enough for aircraft use has been developed. It has great future possibilities because it indicates the true North pole, and is, therefore, the ideal in compass construction. Its directive force is obtained mechanically by means of a rotating gyro which automatically aligns its axis with the true axis of the earth. The principle of this compass is derived from Foucalt's Law, which states that a spinning body (the gyroscope) tends to swing around so as to place its axis parallel to the axis of any impressed force (the force in this case being the earth spinning on its axis).

2. **Sun Compass** — The sun compass is a special instrument designed for use in polar regions where the magnetic compass may be uncertain. It indicates direction by means of the sun, utilizing the principle of the sun dial. It has to be set continuously to local apparent time, and the sun's shadow indicates direction of flight.

## MAGNETIC COMPASS

**Description** — Though many attempts are being made to develop compasses operating on various scientific principles, the magnetic compass, greatly refined since the ancient navigator's floating lodestone, is still the most dependable and least liable to mechanical failure. For this reason, and also because it is the most fundamental of all navigational instruments, the magnetic compass should be thoroughly understood by the navigator.

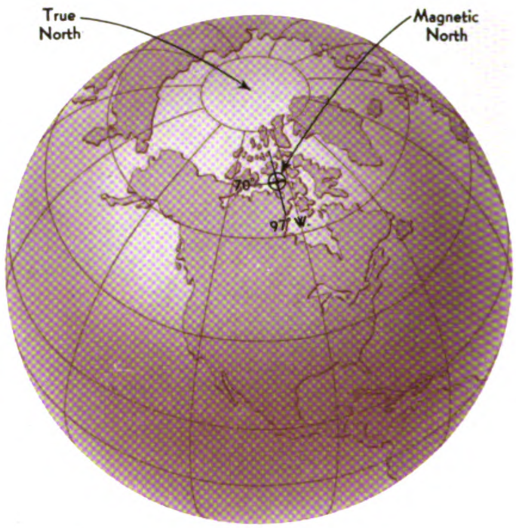


**FIG 24—LOCATION OF MAGNETIC NORTH**

**The Directive Force** of the magnetic compass is the magnetic field surrounding the earth. The magnetic compass, therefore, does not point to the true North pole but towards the magnetic North pole, which is approximately 1200 miles away from the true North pole, just north of Hudson Bay in about latitude 70° North, longitude 97° West (Figure 24). This difference between true North and magnetic North causes an error in the compass reading known as variation, which will be discussed thoroughly later on.

**Principle** — From elementary physics one learns that when two magnets are brought together, like poles repel and unlike poles attract



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each other. Also, that the earth itself exhibits the properties of a great magnet, having North and South magnetic poles (Figure 25). Therefore, when a magnet is fully supported in space and is free to rotate in a horizontal plane, it tends to align itself with the earth's magnetic field, its ends pointing toward the North and South magnetic poles.

**Dip**—Notice in Figure 25 that the magnetic lines of force are parallel to the earth's surface at the magnetic equator, but that on either side of the equator they dip toward the poles, becoming vertical at the poles themselves. Because of this fact, the compass magnets also dip toward the poles appreciably in higher latitudes. For this reason the magnetic compass is not reliable in polar regions.

**The Basic Construction** of all magnetic compasses is similar, consisting of a card, graduated in degrees, to which is attached a magnet, or group of magnets, parallel to the North and South axis of the card. The whole card assembly, freely supported on a pivot, is contained in a non-magnetic bowl.

**There Are Many Types** of magnetic compass which have been developed for aviation and marine use, each designed for best performance under different conditions, but all constructed on the same basic principle. Two magnetic compasses, of different types, usually are installed in airplanes designed for long-range flying. They are:

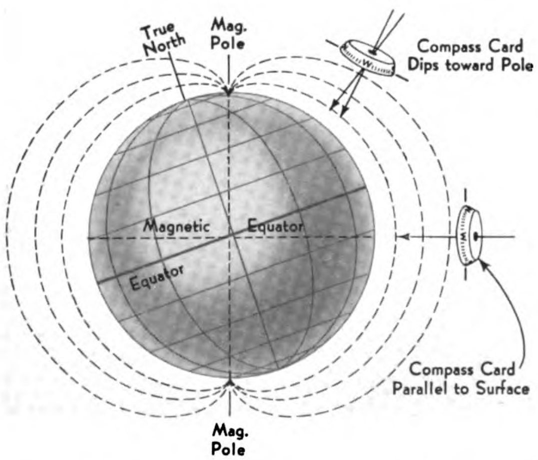


FIG. 25—EARTH'S MAGNETIC FIELD

Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

FIG. 26—APERIODIC COMPASS

1. Aperiodic compass (the navigator's compass) (Figure 26).
2. Pilot's compass (Figure 27).

The aperiodic compass was designed especially for aerial navigation. It is easy to read and is so constructed that the compass card, when deflected from a position of equilibrium, will return to its heading slowly and positively and will not oscillate about the point of reading.

**The Principal Parts** of the magnetic compass (Figure 27) are the following:

1. **The Compass Card** usually is graduated in degrees. The four cardinal points (North, East, South and West) are lettered N, E, S, W. Some compasses, such as the aperiodic, show 1° graduations, but many of the pilots' type have only 5° graduations with every 30° numbered. The pilots' type compass is viewed from the side opposite its heading. The N marking, if viewed from the top, would actually be on the South end of the card. Because this compass is viewed "in reverse," the degree markings are backwards. Therefore, a change of heading causes the card to appear as though it were turning in the wrong direction.

2. **The Magnetic Elements** which supply the directive force to the card usually consist of a small bundle of hardened steel, magnetized needles. Magnetized needles are used because their magnetic influence is stronger than that of a single magnet. Two or more of these ele-



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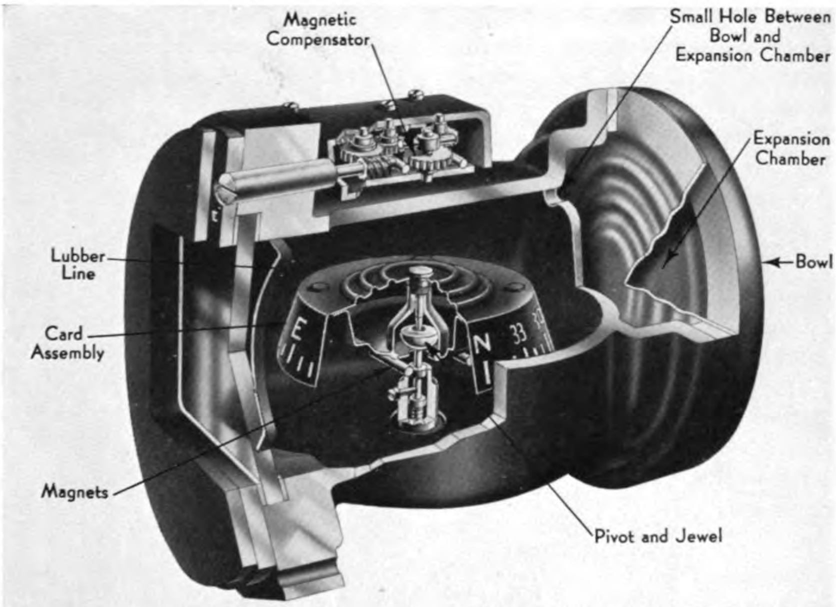


Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

**FIG. 27—PILOTS' TYPE MAGNETIC COMPASS**

ments are secured to the underside of the compass card parallel to the North and South axis.

**3. Pivot and Jewel**—The pivot, made of hardened steel, balances the card and magnets on a jeweled support, usually a sapphire. This arrangement reduces friction and wear so that the card and magnets are as freely suspended as possible. A shock-absorbing spring keeps the pivot on the jewel and also insures maximum protection from vibration.

**4. The Bowl** is cylindrical. It is constructed of non-magnetic material to provide a housing for the card assembly and a container for the dampening fluid.

**5. The Lubber's Line** is usually a thin wire fixed to the center line of the bowl just clear of the freely-moving card assembly. Since the card always points in the direction of magnetic North, when the bowl is turned (as the airplane turns) the lubber's line, fixed to it, also turns and so indicates the amount of turn on the graduated card.

**6. The Dampening Fluid** is colorless, acid-free kerosene which completely fills the bowl. Its purpose is to dampen excessive oscillations of the card assembly, and to reduce shock, vibration, and friction of the pivot by supporting most of the weight of the card assembly. It also prevents corrosion and keeps the jewel washed clean of foreign matter.

**7. The Expansion Chamber** is either a thin metal diaphragm, located in the liquid, or a hollow chamber in the top of the bowl, which keeps the bowl completely filled at all times by balancing the expansion of the liquid due to temperature changes.

**8. Compensating Magnets** usually consist of two sets of screw-adjustable magnets located either above or directly beneath the compass card. Both sets of magnets are arranged in the horizontal plane, but one set is placed so that it will lie on the fore and aft axis of the airplane, and the other so that it will lie on the athwartship axis. These magnets set up a compensating field which, when properly adjusted, greatly reduces the error known as *deviation*. Deviation is caused by local disturbing magnetic forces inherent in the aircraft itself, such as those created by engines, ferrous metals, and electrical circuits.

**Location and Installation**—The magnetic compass should be located where it may be easily read, but as far removed as possible from all sources of artificial magnetic disturbance. All direct current wires nearby should be closely twisted or they will set up a magnetic



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field. The compass should be installed so that the planes of the lubber's line and the card pivot are vertical and parallel to the fore and aft axis of the aircraft. When so installed, the lubber's line will indicate the correct heading on the compass card, and the card assembly itself will be level in normal flight.

**Compensation**—To compensate a compass means to remove as completely as possible all error due to local disturbing magnetic forces existing in the aircraft. The procedure follows:

a. Before starting to compensate, place the airplane on some part of the field free from any artificial magnetic disturbance, such as power lines, pipes and steel structures.

b. Determine the correct magnetic heading of the airplane. There are two recognized methods of doing this:

By reference to a magnetic compass rose.

By means of a pelorus.

(1) **By Compass Rose.** This is the easiest and most common method. The magnetic compass rose is a large compass card laid out on the ground to indicate correct magnetic directions at every 15° or 30° throughout the 360°, starting at magnetic North. It is large enough so that the aircraft being compensated may be accurately headed on each of these 15° intervals.

(2) **By Pelorus.** The pelorus is a dummy compass card upon which sighting vanes may be arranged to take bearings on distant objects. These distant objects may either be objects on the earth, or celestial bodies (usually the sun). For compass compensation the magnetic bearing of the object to be used is first determined. The airplane may then be directed on any correct magnetic heading by reference to the pre-determined bearing. Knowing this method is of advantage because it may be used in the air to check compass error while flying a constant heading.

To continue compensation procedure:

c. Center compensating magnets, or, if they are the removable type, remove them.

d. Simulate all conditions of normal cruising operation and reduce to a minimum any deviation error caused by electro-magnetic influences (by shifting position of, and twisting together, direct current wires). With tail elevated and engines running, turn on and off the radio receiver, radio transmitter, navigation lights, panel lights, Pitot-static tube heater, and generator. Check position of head sets, control positions and engine operation. Check individually and in practical combinations, on every 30° heading, the effect on the compass of these various influences. Any deviation remaining should not exceed 15°, and the ideal would be 0°. The compass is now ready for compensation.

e. Adjust compensating magnets to reduce remaining deviation as much as possible by the following procedure:

(a) Head the aircraft correct magnetic North. Adjust athwartship magnet (marked "N.S."), with a non-magnetic screwdriver, so the compass reads "N."

(b) Head the aircraft correct magnetic East. Adjust fore and aft magnet (marked "E.W.") so compass reads "E."

(c) Head the aircraft correct magnetic South. Adjust "N.S." magnet to *reduce by one-half* any error remaining on this heading.

(d) Head the aircraft correct magnetic West. Adjust "E.W." magnet to *reduce by one-half* any error remaining on this heading.

The deviation error in the compass now has been corrected for as much as possible, and the remaining error will have to be recorded and applied to all headings flown.

**Calibration**—Calibration is the determination and recording of existing deviation error, for use in flight. The amount of deviation error remaining in the compass on each compass heading is determined by swinging the aircraft through a complete circle and recording the error on each 15° heading. The error also should be recorded for actual flight conditions with radio and lights, on and off. With this information a curve of the deviation error is plotted which shows the amount of correction to be applied to any heading. A calibration graph is shown in Figure 28.

As is apparent from the above discussion, there are two basic errors in all magnetic compasses, namely, *variation* and *deviation*.

**Variation**—Variation is the angular difference, measured at the airplane, between *true North* and *magnetic North* (Figure 29).

The amount of variation error affecting a magnetic compass generally ranges from 0° to



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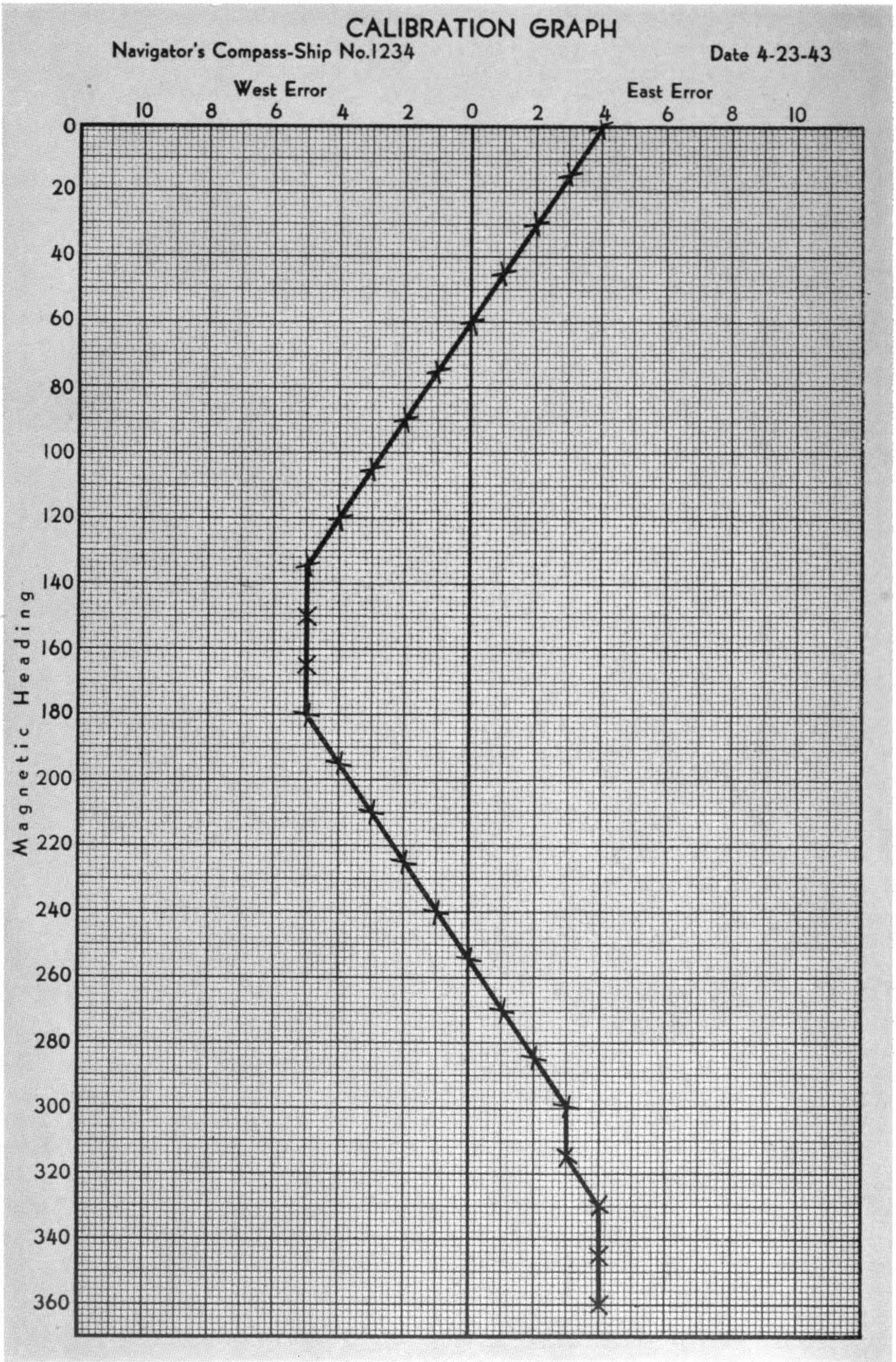


FIG. 28



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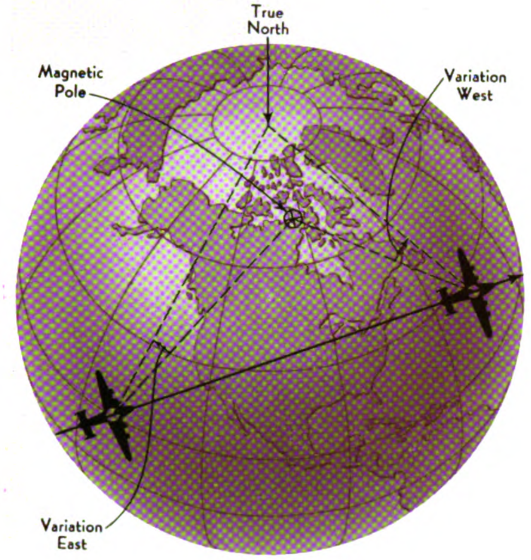


FIG. 29—VARIATION

about 40°, either East or West, depending upon an aircraft's geographical position. However, in polar regions variation up to 180° may be encountered. Besides changing with a plane's geographical position, variation also undergoes a *progressive annual change* which in the course of several years becomes appreciable, but which need not be considered for shorter periods.

*The amount of variation for different geographical positions on the earth is indicated on all air navigation charts by lines connecting points of equal magnetic variation called isogonic lines. The line connecting points of zero variation, found wherever the plane's position is in line with the true and magnetic poles, is called the agonic line. The amount of annual change of variation also is noted on the face of the chart.*

**Deviation**—Deviation is the angular difference, measured at the airplane, between *compass North* and *magnetic North* (Figure 30), compass North being the direction indicated by the compass needle.

Deviation error, as can be seen on the calibration chart (Figure 28), varies for each different heading of the aircraft. Therefore, it has to be applied on every change of heading. This error is recorded as accurately as possible. However, many conditions in the air may cause it to vary. These may be local magnetic attractions in the area being flown over, or acceleration and swirl errors caused by speed, turns and vibrations, or mechanical failure of the compass itself. These additional errors may be reduced somewhat by lightly tapping the compass before reading, and only reading it when flying straight and level at a constant speed.

**Note:** Great stress has been placed by some writers of aerial navigation textbooks on the importance of knowing exact deviation. The author agrees that if the navigator were entirely dependent upon dead reckoning, such knowledge would be essential. He wishes to point out, however, that it seldom is necessary for the long-range aerial navigator to depend solely upon dead reckoning for more than a few hours. Usually it is possible to check the plane's position either by visual or celestial fixes. When this is possible, temporary changes in deviation from those tabulated cease to be a serious consideration, since any unknown compass error simply combines with the unknown wind to yield a total error which can be accurately determined between fixes. This would, of course, mean that the wind calculated would not be entirely accurate since it

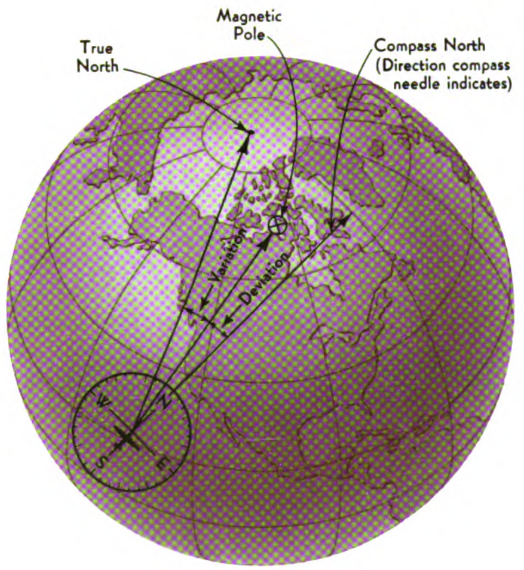


FIG. 30—DEVIATION



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would include some deviation error not known, hence not allowed for. And while error in reporting the existing winds is certainly undesirable from a meteorological viewpoint, it in no way endangers the safety of the aircraft. Thus there is no real basis for the rather prevalent belief that an aircraft will become lost if exact deviation is not known. (Application of compass errors is covered in Chapter III).

## ALTIMETER

**Description**—An aircraft altimeter (Figure 31) is an instrument which measures existing air pressure in the same way as does a barometer, the only difference being that the altimeter scale is graduated to read in feet of altitude rather than inches of mercury.

**Indicated Reading Errors**

1. **Constant Error** is instrument error of a permanent nature which can be calibrated, hence compensated for by proper application of the calibration correction to each instrument reading. Such error usually is due either to faulty construction or installation of the instrument. However, such error does not always exist.

2. **Variable Error** is caused by variations in atmospheric pressure and changes in temperature. This error likewise may be corrected if existing conditions are known. Since the instrument is actuated by atmospheric pressure, which is a variable factor, the manufacturer graduates the instrument card under artificial, simulated standard conditions.

Knob Adjusts Dial to Barometric Setting

FIG. 31—ALTIMETER

Standard conditions are:

At sea level—

Air pressure = 29.92″ Hg.

Temperature = +15°C.

For change in altitude—

Air pressure decreases approximately one-half for each increase in altitude of 18,000 feet.

Temperature lapse rate is approximately 2 C per 1000 feet.

Due to changing weather phenomena, these standard conditions seldom are encountered. Therefore, it is apparent that an instrument graduated to standard conditions normally would read with a certain amount of error. To compensate the indicated reading for variable air pressure, a knob is provided on the altimeter which enables the dial to be rotated to agree with actual barometric pressure. Temperature variations are accounted for by calculation.

**Altimeter Uses**—The altimeter measures the altitude of the aircraft above any given point on the earth's surface. Therefore, it may be used for two purposes:

1. To measure the aircraft's height above an airport, regardless of the airport's altitude, or
2. To measure the height of the aircraft above sea level.

In over-ocean navigation, the navigator is interested primarily in the true altitude above sea level, obtained as follows:

a. Set altimeter to *standard sea level pressure* (29.92″ Hg.). The altimeter then will read as *pressure altitude*.

b. Note outside *air temperature*.

c. Again adjust altimeter to latest *known barometric pressure*. The altimeter then will read as *indicated altitude*. (This barometric pressure may be obtained by radio contact with the nearest ground station or from the isobars indicated on the latest weather map).

d. On the computer set *air temperature* opposite *pressure altitude*. Read *true altitude* opposite *indicated altitude*. (Computers vary slightly but give similar results).

## AIRSPEED INDICATOR

**Description**—The airspeed indicator (Figure 32) is an instrument for measuring the aircraft's speed with reference to surrounding air.



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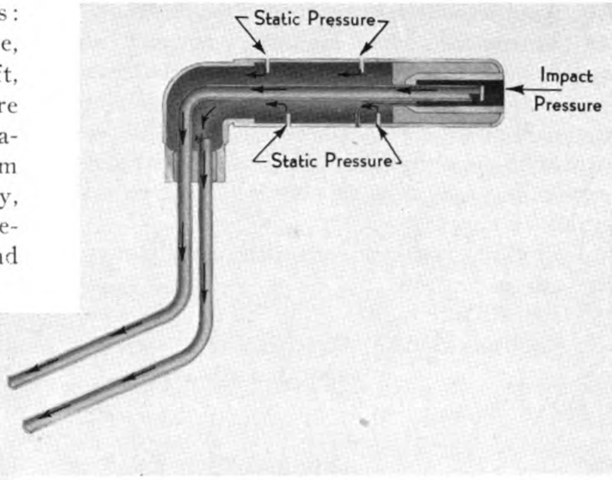
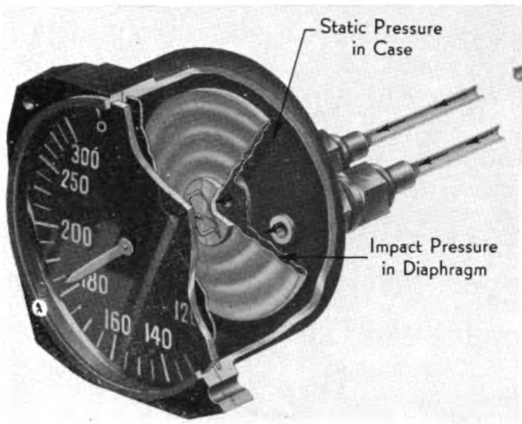
The principle of operation is as follows: A tube, known as the Pitot (pee-tow) tube, is placed forward, outside of the aircraft, and clear of the slipstream. Impact air pressure upon this tube is relayed to a metallic diaphragm inside the instrument. The diaphragm also is affected by existing atmospheric density, and in order that the diaphragm will be responsive to true barometric pressure, a second




Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

FIG. 32—AIRSPEED METER AND PITOT TUBE

tube, called the static tube, is mounted alongside the impact tube. The static tube relays the actual, static atmospheric pressure outside the aircraft to the interior of the airspeed meter case surrounding the metallic diaphragm. The excess of impact pressure over static pressure expands the diaphragm, which in turn actuates a dial graduated in terms of air speed at sea level and under standard atmospheric conditions.

The impact tube and static tube mounted together are called the Pitot-static tube. In some newer installations, the Pitot and static tubes are mounted separately.

The airspeed indicator does not indicate the true air speed of the aircraft, mainly because of installation errors and the fact that it is actuated by variable atmospheric pressure. For this reason the following terms are employed to indicate what corrections, if any, have been applied.

Indicated air speed
Calibrated air speed
True air speed

**Indicated Air Speed**—Indicated air speed is the speed as read on the instrument.

It is based upon standard velocity head values at sea level and standard atmospheric pressure. It does not, however, take into account variations in pressure altitude, air temperature or Pitot-static tube installation errors. Therefore, it is necessary to apply certain corrections to obtain true air speed.

Some aircraft airspeed indicators read directly in knots, although most indicators read in statute miles. In ocean aerial navigation, all distances are measured in nautical miles. Therefore, if the aircraft is equipped with an instrument graduated to read in statute miles, convert the reading into nautical miles before applying further corrections.

*Example*: 175 m.p.h. indicated = 152 knots indicated.

**Calibrated Air Speed**—Calibrated air speed is simply *correct indicated air speed*, i.e., instrument reading corrected for *Pitot-static tube installation error* and minor instrument *calibration error*.

The instrument error usually is slight, but the installation errors in some aircraft are quite large, depending upon the location of the Pitot-static tube.

Several methods are employed for finding the corrections which must be applied to indicated air speed in order to determine calibrated air speed (correct indicated air speed).

One method often used is to fly over a measured course at various speeds, noting the elapsed time.



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Another method is to trail a "static bomb," an instrument which indicates correct air speed, having previously been calibrated in a wind tunnel. Regardless of the method used, the calibrated air speed, when found, is recorded in each individual ship along with corresponding indicated air speeds for future reference in flight.

Flight performance manuals usually show the calibration thus:

For PBY:

Indicated air speed of 102 knots = calibrated 109 knots.

For B-24:

Indicated air speed of 175 m.p.h = calibrated 176 m.p.h.

**Note:** Calibration error correction for different speeds varies but slightly. Therefore, the same amount of calibration error correction is applied to all indicated air speeds.

**True Air Speed**—True air speed is the actual speed of the aircraft with reference to the surrounding air, and is obtained by *correcting the calibrated air speed (correct indicated air speed) for existing temperature and pressure altitude of the aircraft.*

The airspeed meter is graduated for sea level and standard atmospheric pressure, but since atmospheric density decreases as altitude increases, the excess of impact pressure over static pressure also decreases, causing the true air speed to be (nearly always) greater than the indicated air speed.

**Air Speed Correction Problems:**

Temperature = +10°C.

Pressure altitude = 10,000 feet.

*Example* No. 1

| | | |
|---|---|---|
| Indicated air speed | = | 102 knots |
| Calibration error correction | = | +7 knots |
| Calibrated air speed | = | 109 knots |
| True air speed | = | 131 knots |

*Example* No. 2

| | | |
|---|---|---|
| Indicated air speed | = | 175 m.p.h. |
| Calibration error correction | = | +1 m.p.h. |
| Calibrated air speed | = | 176 m.p.h. |
| Calibrated air speed | = | 153 knots |
| True air speed | = | 183 knots |

**Note:** (Use the aircraft computer in converting m.p.h. into knots and in finding true air speed from calibrated air speed).

## THERMOMETER

**Description**—The thermometer is an instrument used to measure the free air temperature outside the aircraft.

It operates on the principle that a substance expands or contracts with an increase or decrease of heat. The aircraft thermometer utilizes a thin, coiled, bi-metallic strip which on expanding or contracting actuates a dial graduated in degrees of temperature.

Two temperature scales commonly used are the Fahrenheit and Centigrade scales. They differ only in the size of graduation intervals.

The Fahrenheit scale is so graduated that 32° equals the freezing point of water and 212° equals the boiling point of water at sea level, under standard atmospheric conditions.

The Centigrade scale, more often used in aircraft, is graduated so that 0° equals the freezing point of water and 100° equals the boiling point.

## CHRONOMETER

**Description**—A chronometer is a very accurate timepiece.

The aircraft chronometer is a watch of exceptionally fine construction and usually has a

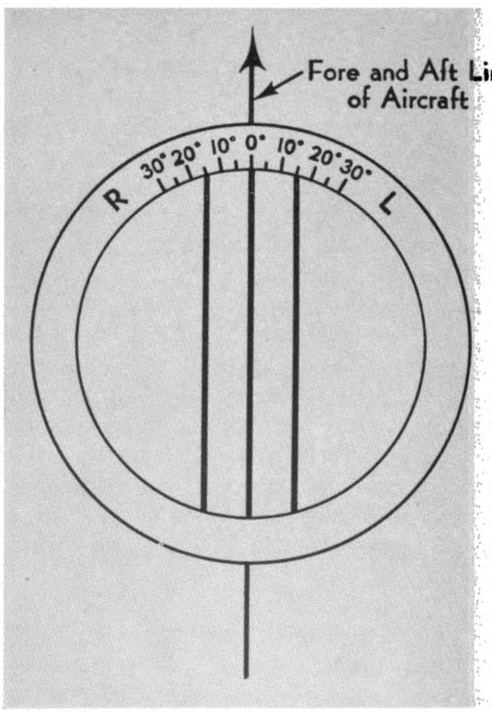


FIG. 33—SIMPLE DRIFT METER



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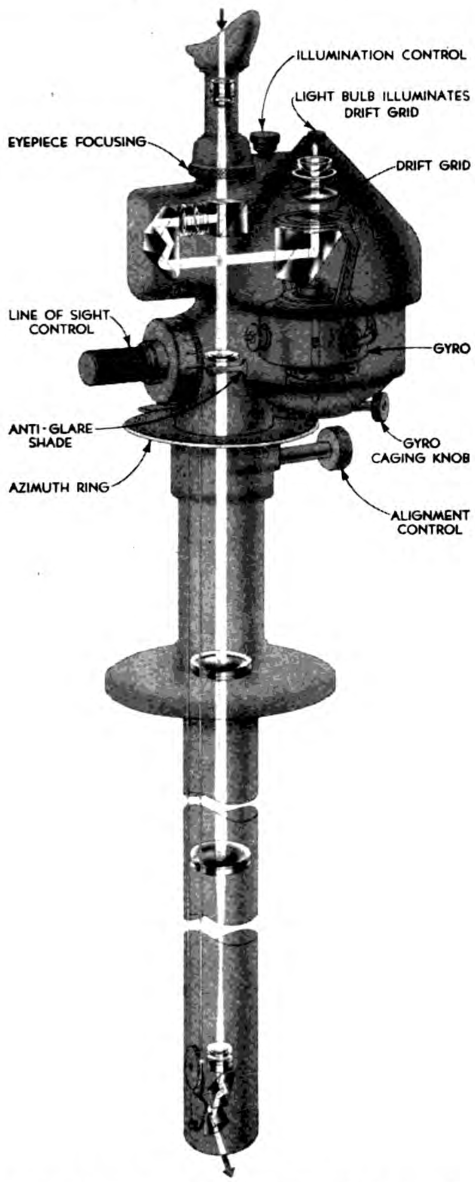


Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

**FIG. 34—TYPE B-3 DRIFT METER**

24-hour dial with a stop-second hand which enables it to be set for zero error. Since it is a precision instrument, it should be handled with the greatest of care. It should be wound at the same time each day, and kept in a case to protect it as much as possible from temperature changes and shock.

The chronometer is set to Greenwich civil time, and should be checked frequently either by reference to a master watch or from radio time signals (ticks), in order to determine its "rate." The rate is the amount it gains or loses each day. As long as the rate is constant and not more than a few seconds each day, a record can be kept so that correct time will always be had by applying the amount of gain or loss since the last accurate check. If the rate is erratic, the watch should be sent to a jeweler for repair.

## DRIFT METER

**General**—Drift represents the effect of crosswind on the aircraft's heading. If the wind's force and direction were accurately known it would be easy to calculate drift. Unfortunately, however, no reliable method yet has been devised to accurately pre-determine the wind force and direction for any proposed flight. Therefore the navigator must use all available methods to measure the aircraft's drift while in the air. The easiest method of doing this is by means of a drift meter, which is an instrument for determining the angle at which an aircraft is drifting to the right or left of its course.

**The Simplest Type** of drift meter (Figure 33) is a grid of parallel lines, installed in an opening in the floor of the aircraft. The center line, when parallel to the fore and aft axis of the aircraft, is marked 0° drift. In flight, the number of degrees to the right or left which the grid must be rotated in order to align the grid lines with the apparent motion of the ground, is the angle of drift.

**A Refined Type** of drift meter is the type B-3* (Figure 34). It utilizes the same principle as the type above described except that the ground is viewed through an optical system, and the grid is kept parallel to the ground by a self-erecting gyroscope. Besides an azimuth scale for reading drift or taking visual bearings through 360°, the B-3 meter incorporates a graduated line of sight control which can be used either for reading drift or measuring the vertical angles used in computing ground speed.

*A complete description of the B-3 drift meter may be found in Air Corps Technical Manual No. 205 or in the Bendix Instruments Manual.



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*Caution*—Many types of drift meter have been devised, and their correct use makes accurate dead reckoning navigation possible. However, it should be remembered that a drift meter is a mechanical device, and therefore liable to error. The drift meter should be used whenever possible, but only as an added help to celestial navigation and other available navigation aids.

**Use of Type B-3 Drift Meter to Measure Drift:**

a. Turn on the gyro and, when it has attained operating speed (3 to 5 minutes), release the gyro caging knob which is located under the gyro housing. The gyro should be released only in level flight and should be caged during maneuvers or when the gyro is not in use.

b. Adjust the light rheostat so that the grid and the image on the ground are easily seen.

c. Rotate the instrument until the apparent motion of a whitecap, object on the ground, or a signal device previously dropped from the aircraft follows the fore and aft grid wires. The drift angle then is read on the azimuth scale.

**Note:** By rotating the line of sight control, the ground object may be viewed directly beneath or to the rear of the aircraft.

**Use of Type B-3 Drift Meter to Determine Ground Speed:** Ground speed may be determined by the following formula after measuring the time (in seconds) it takes for an object on the ground to pass over a convenient angle, measured on the line of sight control.

Formula for ground speed—

$$\text{Ground speed} = \frac{\text{Altitude}}{\text{Time}} \times \text{Factor}$$

[For factor see factor table (Figure 35)]

One procedure is as follows:

a. Determine the true altitude.

b. Uncage gyro and allow five minutes for it to erect itself.

c. With the line of sight control set at 0° (starting angle), sight a ground object on the center athwartship grid wire and follow its motion by revolving the line of sight control for ten seconds. (The line of sight control may be set other than at 0° at start and the time allowed may be other than 10 seconds; however, the method cited simplifies solution.)

d. Read the angle on the line of sight control (finish angle) and obtain the factor by inspection of the factor table (Figure 35).

e. Compute formula.

*Example* No. 1
True altitude = 10,000 feet
Start on line of sight control 0°, finish 18°
Total time = 10 seconds.

$$\frac{10{,}000 \text{ ft.}}{10 \text{ sec.}} \times .1932 =$$

$$1{,}000 \times .1932 =$$

193.2 knots ground speed.

**Note:** Factor (.1932) is for finish angle 18° and is found by interpolating between 15° and 20° as follows:

.159 = 15° factor
.216 = 20° factor
.057 = difference

Interpolating—
3/5 of .057 = .0342
.159 = 15° factor
+.0342 = 3° of difference
.1932 = 18° factor

**FACTOR TABLE FOR GROUND SPEED**
**(In Knots)**

| Finish Angle | Starting Angle 0° | 10° | 20° | 30° | 40° | 50° |
|---|---|---|---|---|---|---|
| 5° | .052 | | | | | |
| 10° | .104 | | | | | |
| 15° | .159 | .054 | | | | |
| 20° | .216 | .111 | | | | |
| 25° | .276 | .172 | .061 | | | |
| 30° | .342 | .238 | .126 | | | |
| 35° | .415 | .310 | .199 | .073 | | |
| 40° | .497 | .392 | .281 | .155 | | |
| 45° | .592 | .488 | .377 | .250 | .095 | |
| 50° | .706 | .601 | .490 | .364 | .209 | |
| 55° | .846 | .741 | .630 | .504 | .349 | .140 |
| 60° | 1.026 | .922 | .810 | .684 | .529 | .320 |
| 65° | 1.270 | 1.165 | 1.054 | .928 | .773 | .564 |
| 70.9° | 1.706 | 1.602 | 1.490 | 1.364 | 1.209 | 1.000 |

FIG. 35

**Practical Alignment** — For accurate drift meter readings it is necessary that the drift wires be parallel with the longitudinal axis of the aircraft, and that the azimuth scale read 0° forward and 180° aft when the drift wires are thus aligned.



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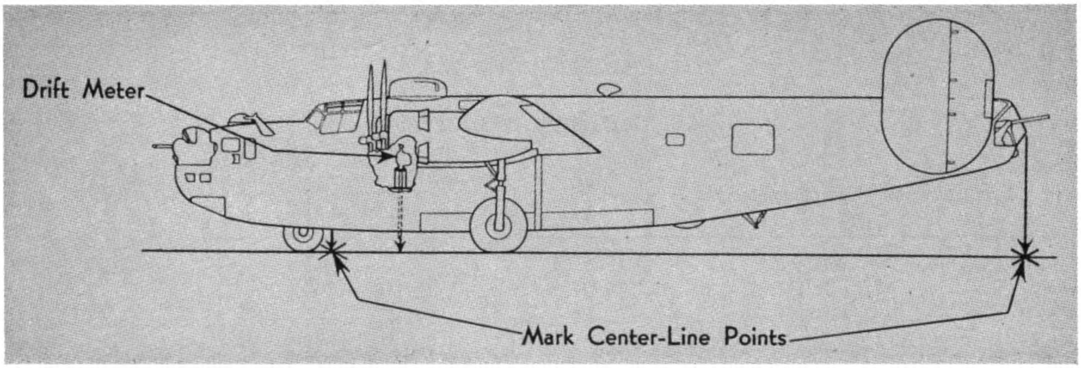


FIG. 36—ALIGNING DRIFT METER (SIDE VIEW)

This alignment may be accomplished quickly and accurately enough for practical navigation by means of a length of string and a plumb bob. The procedure is as follows: (see Figures 36 and 37)

a. Establish center line of aircraft by dropping a plumb bob from center of tail and center of nose (or center line behind nose wheel, if tricycle landing gear). (Figure 36)

b. Drop plumb bob from center of drift meter coverglass, and mark point vertically beneath on ground. Measure distance of this point from center line and then measure out a similar distance from the fore and aft center points. Through these three points hold a string parallel to center line (Figure 37).

c. Rotate drift meter, with gyro caged, sighting the string line fore and aft by turning line of sight control until parallel wires of drift meter are aligned with string line. Azimuth drift scale should then indicate 0° forward; if not, loosen screws and adjust azimuth ring.

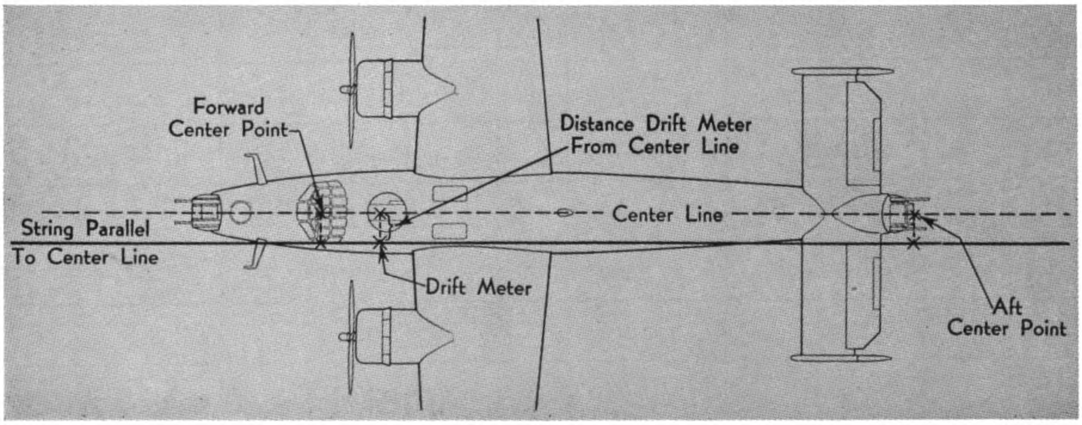


FIG. 37—ALIGNING DRIFT METER (TOP VIEW)

## PROBLEM WORK

No. 3 Draw diagram of pilots' type magnetic compass and indicate the principal parts.



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**PROBLEM WORK NO. 4**

**ALTIMETER CORRECTION**

(Find true altitude. Use computer.)

| No. | PRESSURE ALTITUDE | INDICATED ALTITUDE | TEMPERATURE | TRUE ALTITUDE |
|---|---|---|---|---|
| 1 | 7500′ | 8000′ | + 10°C | |
| 2 | 3300′ | 3000′ | + 15°C | |
| 3 | 24,000′ | 23,000′ | − 22°F | |
| 4 | 10,000′ | 11,000′ | 0°C | |
| 5 | 4500′ | 5000′ | + 15°C | |
| 6 | 16,400′ | 17,000′ | + 14°C | |
| 7 | 1700′ | 2000′ | + 10°C | |
| 8 | 8000′ | 8400′ | + 18°C | |
| 9 | 17,000′ | 16,500′ | + 32°F | |
| 10 | 15,000′ | 14,000′ | 0°F | |
| 11 | 5500′ | 6000′ | + 12°C | |
| 12 | 1000′ | 1300′ | +100°F | |
| 13 | 2750′ | 3000′ | − 7°C | |
| 14 | 10,000′ | 9500′ | + 15°C | |
| 15 | 8500′ | 8000′ | + 15°C | |
| 16 | 6000′ | 5900′ | + 20°C | |
| 17 | 7500′ | 7500′ | 0°C | |
| 18 | 9500′ | 10,000′ | − 5°C | |
| 19 | 8000′ | 8500′ | + 42°F | |
| 20 | 13,000′ | 12,400′ | − 16°C | |



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**PROBLEM WORK NO. 5**

**AIR SPEED CORRECTION**

(Find missing air speeds. Use computer.)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| If I. A.S in m.p.h. = | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 |
| Then C.A.S. in m.p.h. = | 90 | 102 | 113 | 124 | 135 | 146 | 157 | 168 | 178 | 185 | 196 | 204 | 212 |

| No. | I.A.S. (m.p.h.) | C.A.S. (m.p.h.) | C.A.S. (knots) | PRESSURE ALTITUDE | TEMP. | T.A.S. (knots) |
|---|---|---|---|---|---|---|
| 1 | 142 | | | 11,000′ | 0°C | |
| 2 | 160 | | | 8000′ | — 3°C | |
| 3 | | | | 6000′ | +42°F | 185 |
| 4 | | | | 9000′ | +21°F | 191 |
| 5 | 163 | | | 7000′ | — 3°C | |
| 6 | | | | 3000′ | +32°F | 165 |
| 7 | 145 | | | 6000′ | + 4°C | |
| 8 | | | | 9000′ | +42°F | 192 |
| 9 | 158 | | | 2000′ | + 1°C | |
| 10 | 139 | | | 4000′ | — 6°C | |
| 11 | 151 | | | 9000′ | +18°C | |
| 12 | | | | 3000′ | — 1°C | 182 |
| 13 | 165 | | | 6000′ | +26°F | |
| 14 | 180 | | | 14,000′ | — 6°C | |
| 15 | 186 | | | 11,000′ | +14°C | |
| 16 | 157 | | | 1000′ | +76°F | |
| 17 | | | | 6000′ | +19°C | 186 |
| 18 | | | | 9000′ | + 6°C | 195 |
| 19 | 180 | | | 8000′ | +14°F | |
| 20 | 121 | | | 3000′ | +23°F | |



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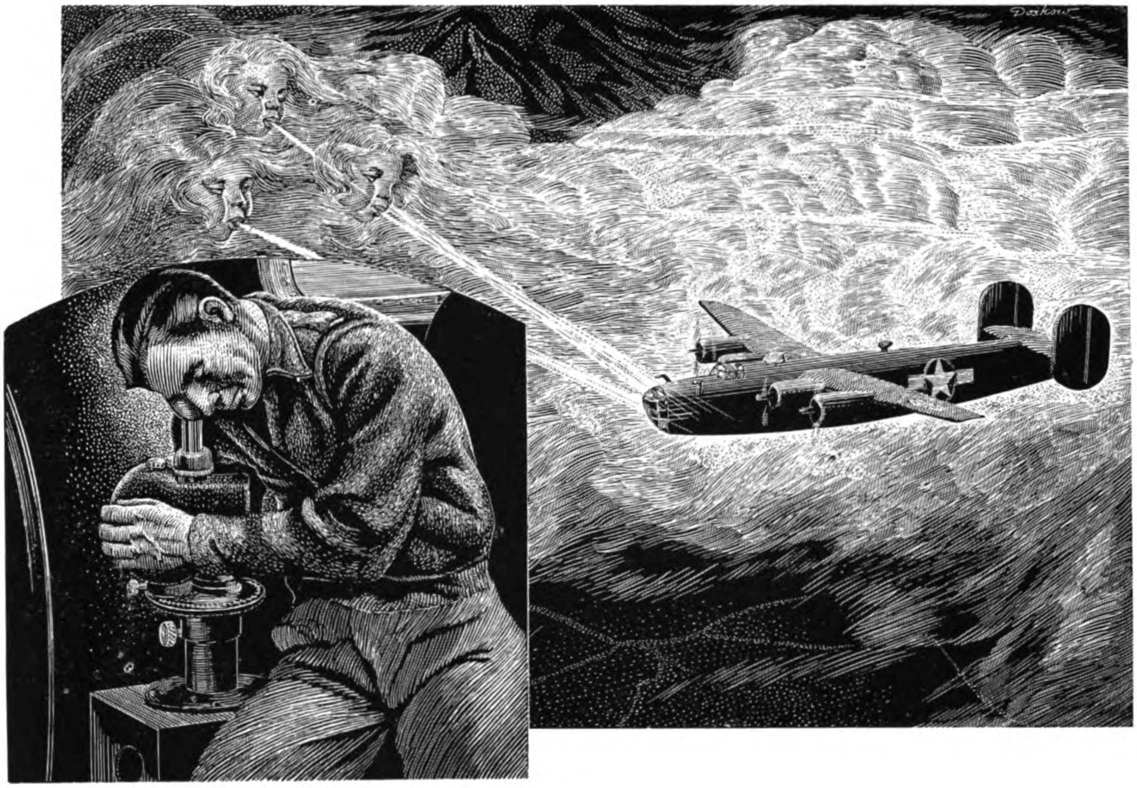

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# DEAD RECKONING

THE term "Dead Reckoning" is commonly supposed to have evolved from "Deduced Reckoning." First, "Ded. Reckoning" as an abbreviation, the form eventually became "Dead Reckoning" for convenience.

**Dead Reckoning** (DR) is the basic method of determining the location of an aircraft with reference to a known position by keeping an account or reckoning of the estimated distance flown and calculated track made good. It involves taking into account all available knowledge of time, speed, drift, heading, track, and weather conditions. If the direction and velocity of the wind actually were known, the dead reckoning position likewise would be very accurate; however, weather data quite often is vague, and different navigators using the same information probably would obtain varying results.

One navigator, after making several flights across the South Atlantic with unusually correct DR calculations (in which luck certainly played a part), applied for employment with a different company. In his application he stated: "I feel I should be hired because of my unusual 'homing pigeon' instinct!" He wasn't hired, as his colorful claim was entirely without foundation.



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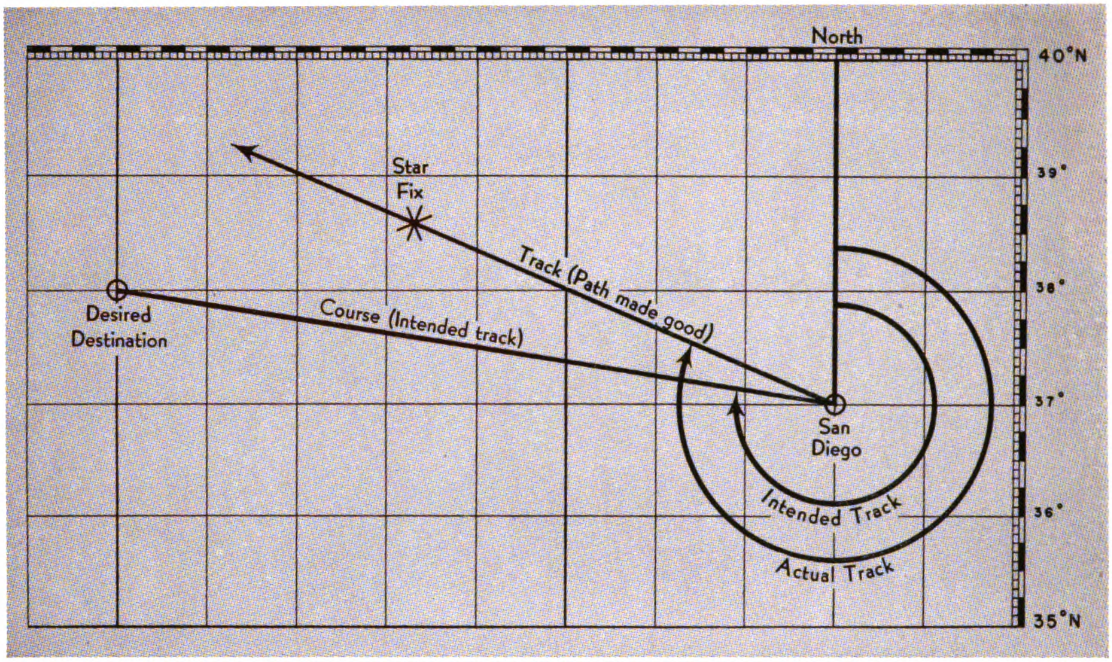


FIG. 38—TRACK AND COURSE

When a navigator continuously calculates fairly accurate DR positions, the "homing pigeon" instinct would more likely be the result of the following:

1. Complete understanding of all methods known of establishing and plotting positions.

2. A working knowledge of wind velocity triangles.

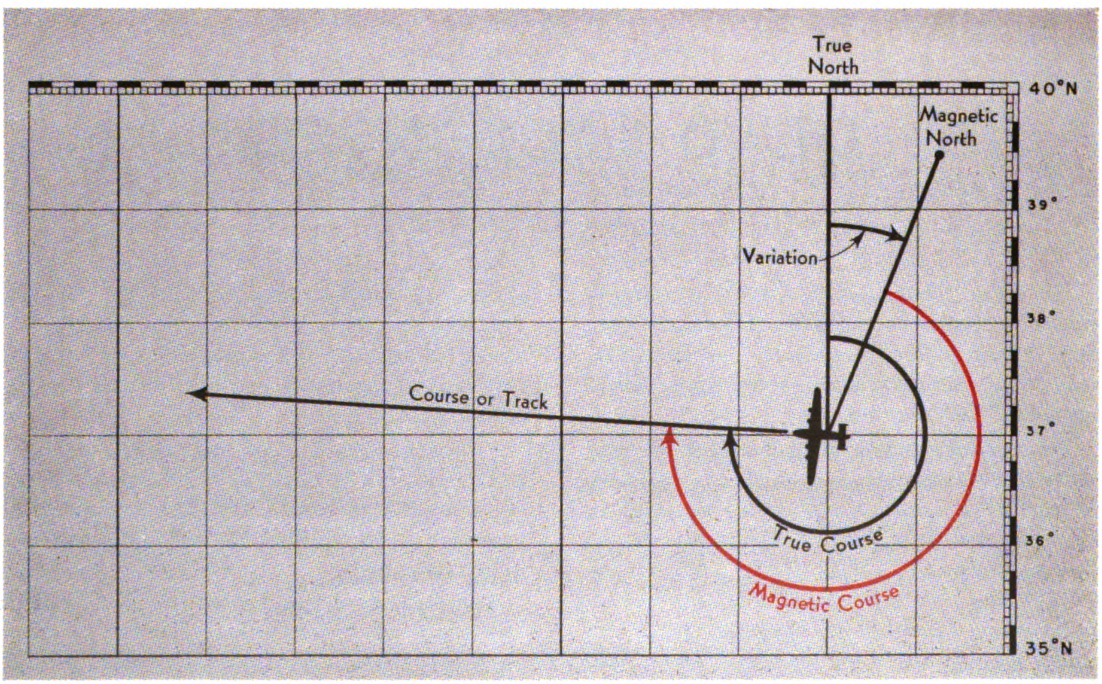


FIG. 39—TRUE AND MAGNETIC COURSE



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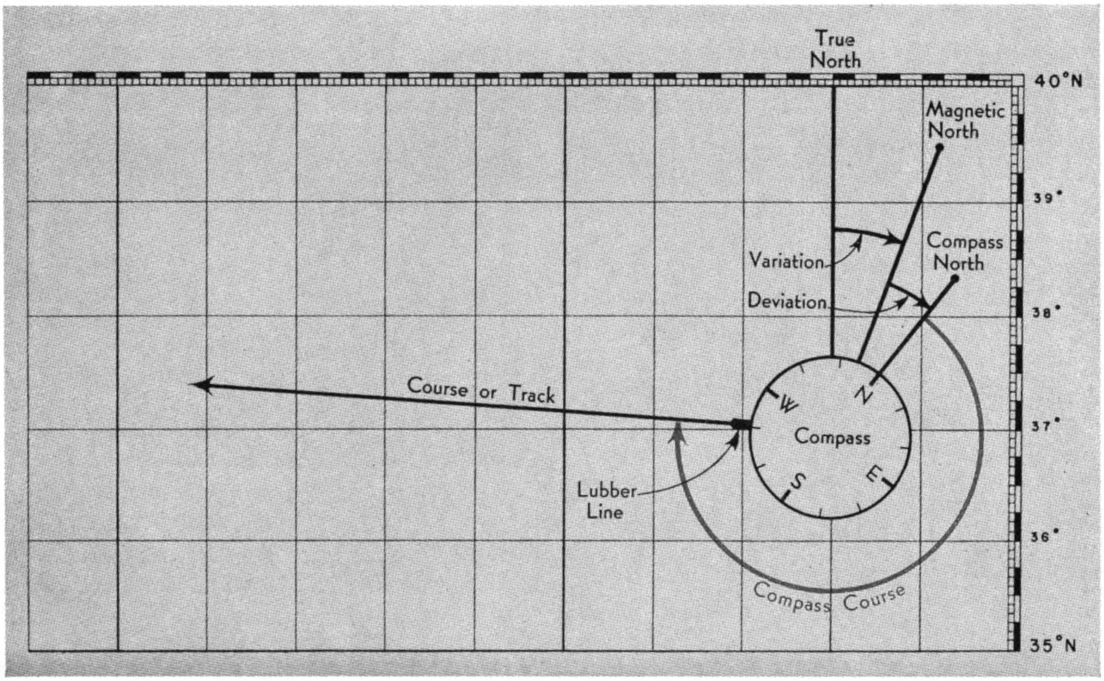


**FIG. 40—COMPASS COURSE**

3. A thorough proficiency in observing drift and the ability to correctly interpret values obtained.

4. Most important of all, the ability through reasoning and deduction from all available data regarding drift and speed, to determine his most probable position.

## TRACK AND COURSE

**Track** is the *path* which the *aircraft actually makes good* over the ground. It is considered to be true track (i.e., measured from true North) unless otherwise indicated. (Figure 38)

**Course** is the *intended track,* i.e., the path which it is *intended* that the aircraft will follow in flying from one point to another over the ground. Unless otherwise indicated, it is considered to be true course. (Figure 38) Reference points from which courses are measured give rise to the following course terms:

1. **True Course** is the angular direction of the course measured from *true North.* It is obtained by applying both variation and deviation to compass course or variation to magnetic course. (Figure 39)

2. **Magnetic Course** is the angular direction of the course measured from magnetic North. It is obtained by applying variation to true course or deviation to compass course. (Figure 39)

3. **Compass Course** is the direction indicated on the magnetic compass. It is the angular direction of the course with reference to compass North, and can be obtained from true course by applying both variation and deviation. (Figure 40)

**Note:** The term "compass course" is used here only for aiding the navigator in visualizing course corrections and for determining compass errors when the aircraft is stationary. In flight the aircraft does not fly a compass course because the direction indicated on the aircraft compass is actually compass heading. Compass heading (see page 33) also is affected by an additional course correction known as drift, which represents the effect of wind on the aircraft.

## APPLYING COMPASS ERRORS

**General**—Orientation of the aircraft with respect to true North is most important to the navigator. However, it is imperative to bear in mind that only by applying the errors of variation and deviation to the magnetic compass reading can the aircraft's direction with respect to true North be obtained.



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Thus it is apparent that true North is obtained *indirectly* from the magnetic compass reading. This simple fact sums up the principle of course conversions. The application of compass errors is not difficult, but must be mastered by the navigator if he is to be reliable.

**Course Relationship**—Course conversion is simplified once the navigator thoroughly understands the relationship of the various course terms to each other. This relationship may be outlined as follows:

True Course: *No error.*

Magnetic Course: *One error*—variation (from true course).

Compass Course: *Two errors*—variation and deviation (from true course).

Therefore

| | (±) | | (±) | |
|---|---|---|---|---|
| True | *Var.* | Magnetic | *Dev.* | Compass |

*Variation* is error between true and magnetic.

*Deviation* is error between magnetic and compass.

**Conversion "Jingle"**—To simplify course conversions, the navigator should adopt some positive method which will:

1. Help him determine the correct application of errors.
2. Double check his course computations.

The following "jingle" may prove helpful:

**"TRUE RIGHT EAST"**
**"TRUE LEFT WEST"**

**TRUE RIGHT EAST** *means*—If error is *East* the more correct course is *right*. (Figure 41)

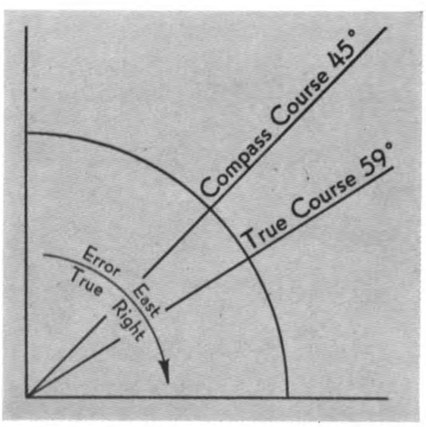


FIG. 41—"TRUE RIGHT EAST"

**TRUE LEFT WEST** *means*—If error is *West* the more correct course is *left*. (Figure 42)

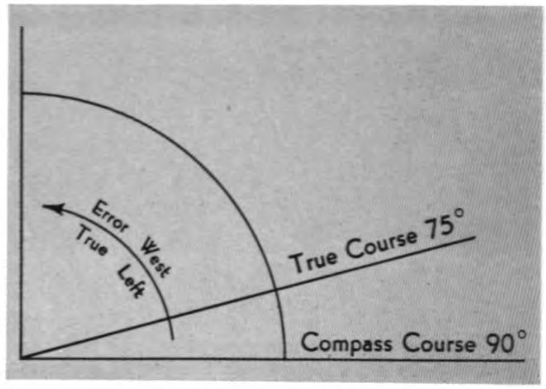


FIG. 42—"TRUE LEFT WEST"

In using the jingle, remember—True course contains no error and therefore is *more correct* than either magnetic or compass course.

Also remember—Magnetic course, containing one error, is *more correct* than compass course, which contains two errors.

*Example* No. 1

The compass course of an aircraft is 45°.

*Required*: True course.

Variation = 18° **East**
Deviation = 4° **West**

Total error = 14° **East**

The *true course,* therefore, is 14° *right* of the *compass course,* hence:

True course = 59°

*Note*: Variation was found on the chart; deviation on the calibration graph, for a course of 45°.

*Example* No. 2

The true course to be flown is 75°.

*Required*: Compass course.

Variation = 20° **West**
Deviation = 5° **East**

Total error = 15° **West**

The *true course,* therefore, is 15° *left* of the *compass course,* hence:

Compass course = 90°.

*Note*: Variation was found on the chart; Deviation, on the calibration graph for a course of 90°.



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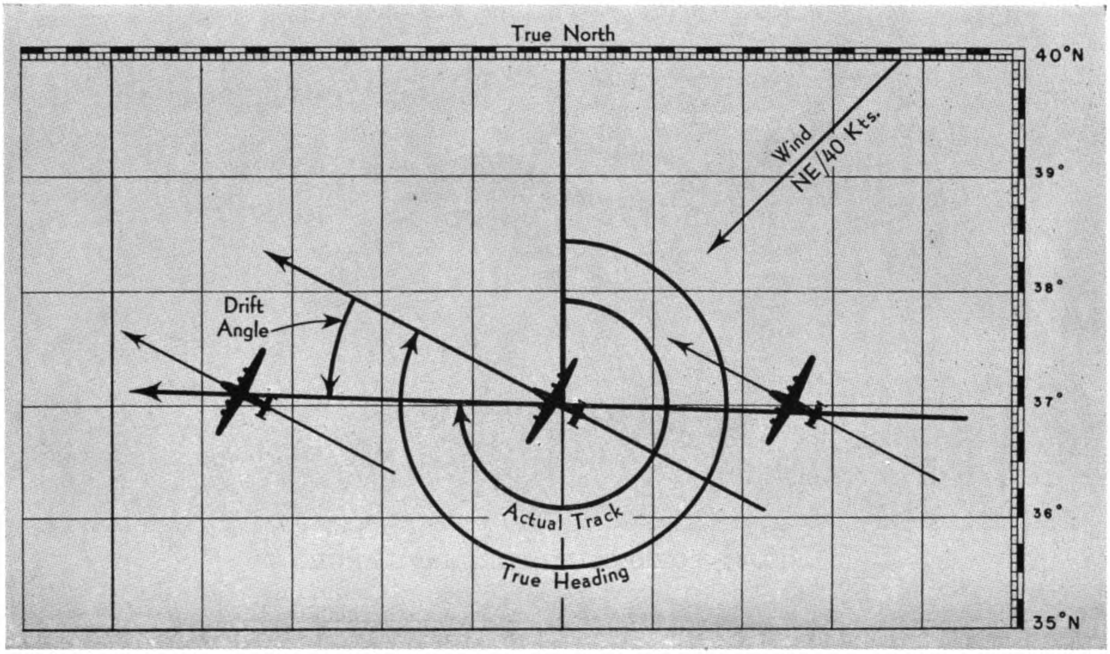


FIG. 43—DRIFT ANGLE AND HEADING

Sometimes compass errors are applied one at a time, as illustrated in examples No. 3 and 4.

*Example* No. 3

| | | |
|---|---|---|
| Compass course | = | 45° |
| Deviation | = — | 4° **West** (magnetic left) |
| Magnetic course | = | 41° |
| Variation | = + | 18° **East** (true right) |
| True course | = | 59° |

*Example* No. 4

| | | |
|---|---|---|
| True course | = | 75° |
| Variation | = + | 20° **West** (true left) |
| Magnetic course | = | 95° |
| Deviation | = — | 5° **East** (mag. right) |
| Compass course | = | 90° |

## DRIFT ANGLE

Drift angle, or drift, represents the effect of crosswind on the aircraft and may be defined as the angular difference between heading and track.

## HEADING

Heading is the direction in which the longitudinal axis of the aircraft is pointed and, except in the case of tail-wind, is always into the wind. (Figure 43) Unless otherwise indicated, it is considered to be true heading. Reference points from which headings are measured give rise to the following heading terms:

1. **True Heading** is the heading of the aircraft measured from true North. It can be obtained by applying drift angle to true course.

2. **Magnetic Heading** is the heading of the aircraft measured from magnetic North. It can be obtained by applying drift angle to magnetic course.

3. **Compass Heading** is the heading of the aircraft measured from compass North. It can be obtained (theoretically) by applying drift angle to compass course. However, as the heading of an aircraft changes, the deviation changes. Therefore, since the drift angle may be large, a more accurate compass heading can be determined if the magnetic heading is computed first, and the compass heading is then computed by applying deviation to the magnetic heading.

**Course-Drift-Heading Relationship** — In Figure 44 it is apparent that when drift angle is applied to any course, the result is heading. Thus it may be assumed that the term "heading" indicates an additional error—drift angle —which for purposes of course conversion can be applied as an additional compass error.



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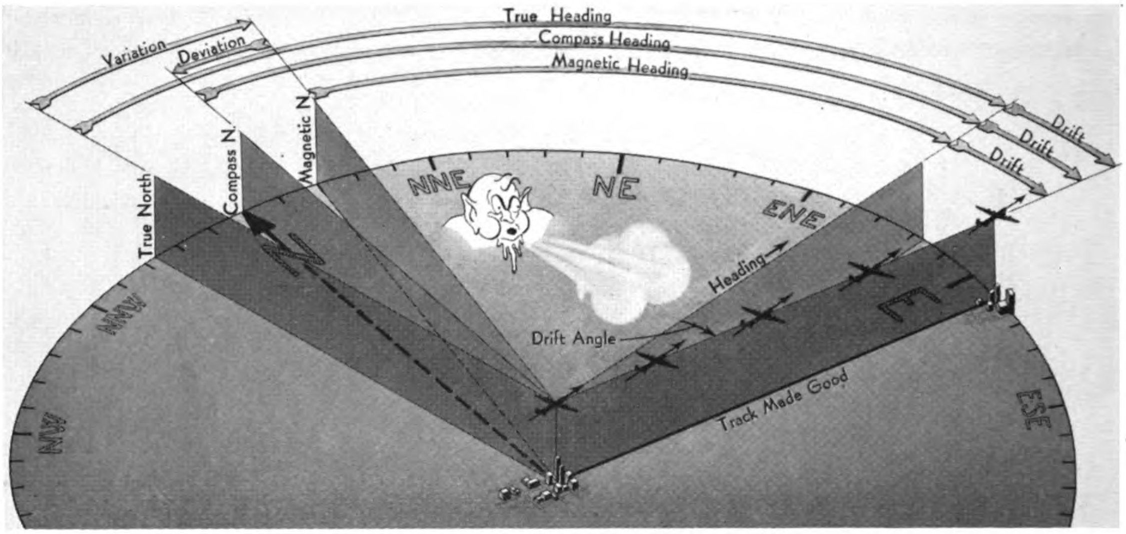


FIG. 44—CORRECTING FOR DRIFT ANGLE

Thus:

True heading: *One error*—drift (from true course).

Magnetic heading: *Two errors*—drift and variation (from true course).

Compass heading: *Three errors*—drift, variation and deviation (from true course).

Therefore, to find the compass heading necessary to fly in order to make good a desired true course, or to determine the true course being flown while steering a certain compass heading, the same jingle—**True Right East—True Left West—**holds good.

*Example* No. 1

To find compass heading necessary to fly in order to make good a desired true course:

| | | |
|---|---|---|
| True course | = 120° | |
| Drift | = 5° | **Right** (true course right) |
| True heading | = 115° | |
| Variation | = 20° | **East** (true right) |
| Magnetic heading | = 95° | |
| Deviation | = 3° | **West** (magnetic left) |
| Compass heading | = 98° | |

*Example* No. 2

To find the true course being flown while steering a certain compass heading:

| | | |
|---|---|---|
| Compass heading | = 320° | |
| Deviation | = 6° | **East** (mag. right) |
| Magnetic heading | = 326° | |
| Variation | = 32° | **West** (true left) |
| True heading | = 294° | |
| Drift | = 14° | **Left** (true course left) |
| True course | = 280° | |

## SPEED

**Ground Speed** is the speed of the aircraft with reference to the ground.

**Air Speed** is the speed of the aircraft with reference to the surrounding air.

**Note:** Ground speed is measured along the true course or track because both ground speed and course or track are related to the ground.

Air speed is measured along the true heading, because both air speed and heading are related to the air.

Where a no-wind condition exists, ground speed and air speed are the same. Where there is wind present, they will differ by a vector amount equal to the velocity of the wind. ("Vector" is defined on page 35).

## TIME—SPEED—DISTANCE

**Time** is the measure of duration which determines how long a plane has flown or can fly.

**Time** = **Distance** divided by **Speed**

*Example*:

$$\frac{\text{480 nautical miles (Distance)}}{\text{150 knots (Speed)}} = \text{3.2 hours or } 3^{h}12^{m}\text{(Time)}$$



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**Speed** is the rate of motion, or *ratio* of *time* and *distance.*

**Speed** = **Distance** divided by **Time**

*Example*:

$$\frac{\text{480 naut. mi. (Distance)}}{\text{3.2 hours (Time)}} = \text{150 knots (Speed)}$$

**Distance** is the measurement of space between two points which determines how far a plane has flown or can fly.

**Distance** = **Time** multiplied by **Speed**

*Example*:

(Time) (Speed) (Distance)
3.2 hours × 150 knots = 480 nautical miles

**Note**: As can be seen from the formulas, time, speed, and distance definitely are related to each other, and each is the result of division or multiplication of the other two. It should be remembered, however, that only like units can be multiplied together or divided by one another to obtain correct results. That is, if distance is in nautical miles, speed will have to be in knots; and, if speed is in knots (nautical miles per hour) then the time must be in hours and *tenths of an hour,* not hours and minutes.

Minutes are converted into tenths of an hour by dividing them by sixty. Similarly, tenths of an hour may be converted into minutes by multiplying them by sixty.

*Example*:

$$\frac{\text{1 minute}}{60} = .017 \text{ hours}$$

$$.017 \text{ hours} \times 60 = 1 \text{ minute}$$

$$\frac{\text{2 minutes}}{60} = .033 \text{ hours}$$

$$.033 \text{ hours} \times 60 = 2 \text{ minutes}$$

$$\frac{\text{3 minutes}}{60} = .05 \text{ hours}$$

$$.05 \text{ hours} \times 60 = 3 \text{ minutes}$$

## VECTOR DIAGRAMS

The term "vector," as used in dead reckoning, refers to a straight line whose *length,* drawn to any chosen scale, represents the *magnitude of a velocity,* and whose *direction* (usually shown by an arrowhead) indicates the *direction of the velocity.* Thus the velocity of an aircraft flying East at 120 knots can be represented graphically by a straight line 120 units in length and directed at an angle of 90° measured clockwise from true North.

Since wind, ground speed and air speed are quantities which have direction and magnitude, they can be represented by vectors. When the three are combined graphically, the result is a *vector diagram,* or *triangle of velocities.* Given sufficient known conditions to permit construction of a vector triangle, the navigator can determine unknown elements by direct measurement. In air navigation, known conditions may be resolved into three basic triangles for determining unknown conditions.

**Three Basic Types:**

*Type* No. 1 (Figure 45)

**Given**: True course or track
True air speed
Wind

**Find**: True heading
Ground speed
Drift

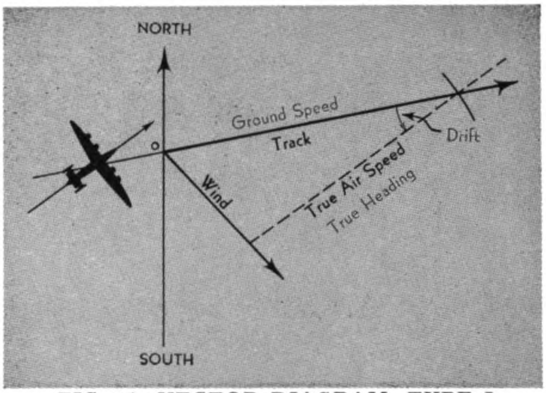


FIG. 45—VECTOR DIAGRAM: TYPE I

*Type* No. 2 (Figure 46)

**Given**: True heading
True air speed
Wind

**Find**: True course or track
Ground speed
Drift

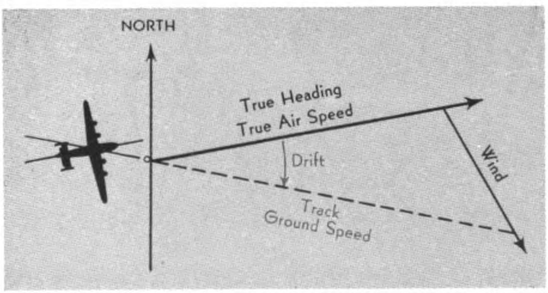


FIG. 46—VECTOR DIAGRAM: TYPE II



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*Type* No. 3 (Figure 47)

**Given:** True course or track
Ground speed
True heading
Air speed
**Find:** Wind
Drift

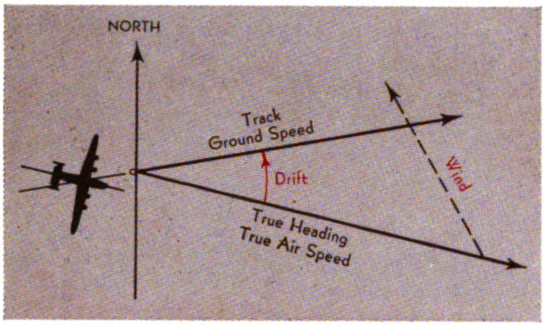


**FIG. 47—VECTOR DIAGRAM: TYPE III**

**Sample Problems:**

*Type* No. 1 (Figure 48)

**Given:** True course = 308°
True air speed = 150 knots
Wind = 20°/35 knots
**Find:** True heading
Ground speed
Drift

*Type* No. 2 (Figure 49)

**Given:** True heading = 250°
True air speed = 125 knots
Wind = 140°/50 knots
**Find:** True course or track
Ground speed
Drift

*Type* No. 3 (Figure 50)

**Given:** Track = 230°
Ground speed = 132 knots
True heading = 245°
True air speed = 175 knots
**Find:** Wind
Drift

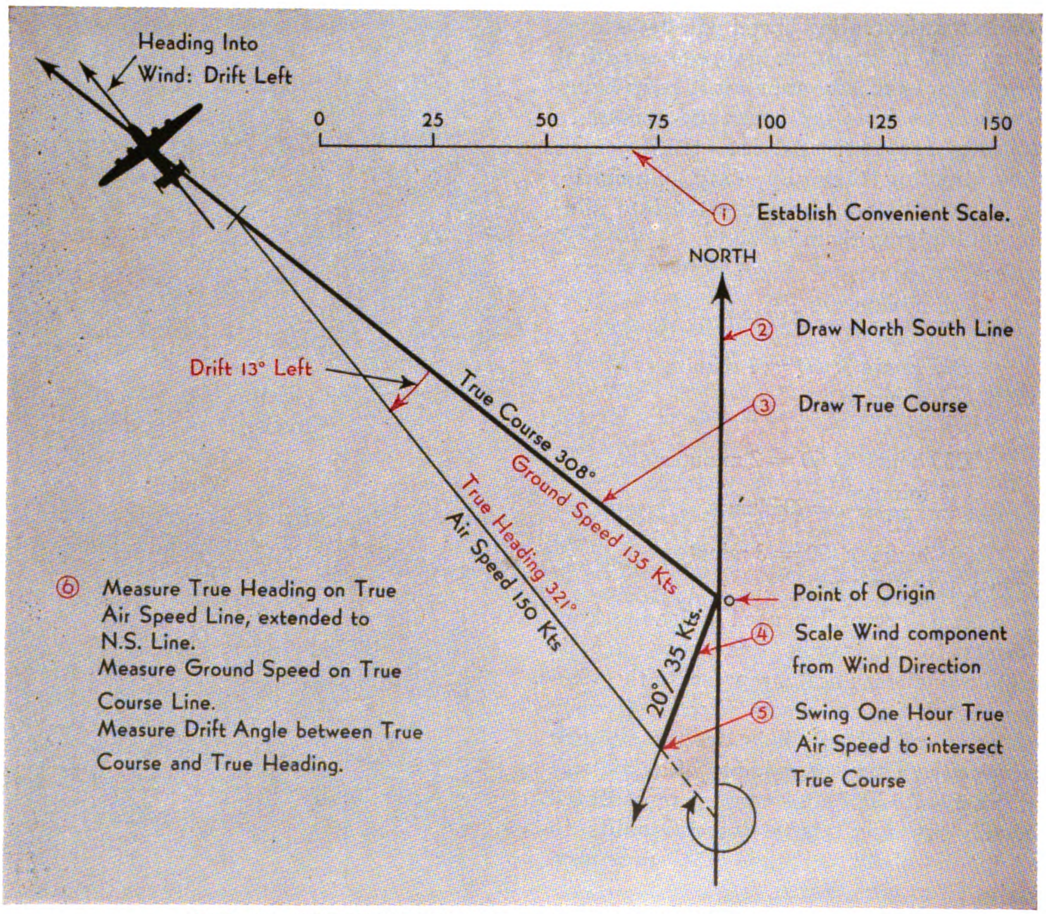


**FIG. 48—APPLICATION OF TYPE I VECTOR DIAGRAM**



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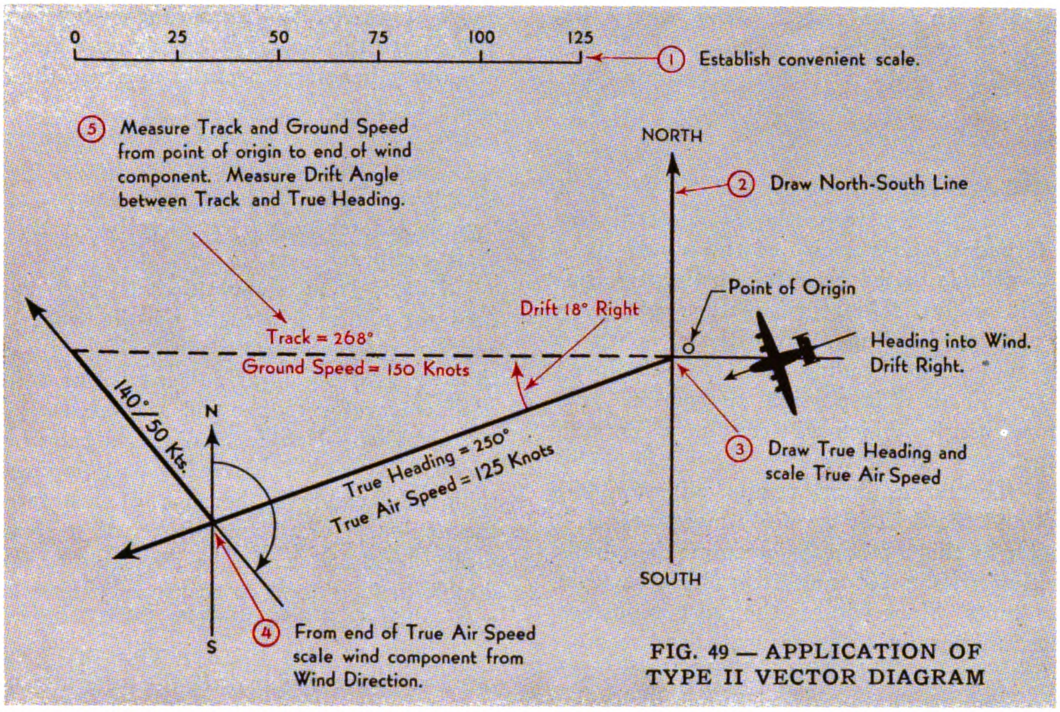


FIG. 49 — APPLICATION OF TYPE II VECTOR DIAGRAM

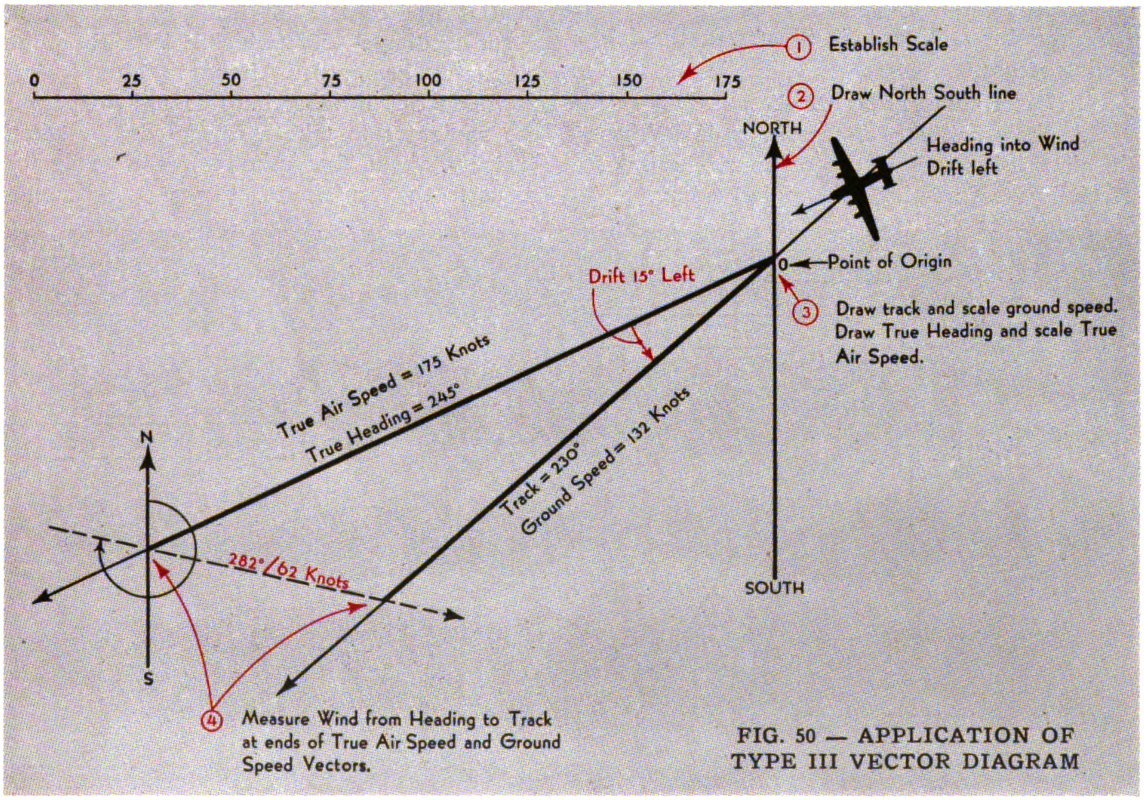


FIG. 50 — APPLICATION OF TYPE III VECTOR DIAGRAM



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**Note:** In actual practice, wind vector triangles are worked on a computer, which permits solution of the problems with a minimum of effort. Knowing their construction, however, helps visualize wind effect.

## DOUBLE DRIFT

Double drift is a method of determining the direction and velocity of the wind at the flight altitude of the aircraft. As the term implies, it involves taking drift meter readings on two separate headings. From the elements of drift angle, true heading, and true air speed thus obtained, it is possible to combine two vector triangles which will contain a common vector, equal to the wind.

If the two headings are approximately 90° apart and the drift is carefully measured, it is possible by this method to determine the wind's direction within 20° and its velocity within three knots. Since wind is the most important factor in determining an accurate dead reckoning position, a double drift is highly important to the ocean navigator, especially when the sky is overcast and navigation is entirely dependent upon dead reckoning.

**Procedure**—Figure 51 illustrates the following steps:

1. Determine *true air speed.*
2. *From on-course heading turn* 45°. When the aircraft is steady in this off-course heading, carefully measure the drift angle reading.
3. *Turn* 90° *back toward the on-course heading.* When the aircraft is steady on this second off-course heading, carefully measure the drift angle reading.
4. *Turn* 45° *to assume on-course heading.*

Then *solve for wind* by the graphic method shown in Figure 52 (sometimes known as the "wind star method"), or directly on the aircraft computer.

**Note:** If the double drift is taken during daylight hours, whitecaps on the waves will serve as reference points with which to line up the drift grid. At night, a flare must be dropped onto the water to provide a reference point.

**Problem**—Unable to obtain a celestial fix because the sky is overcast, and finding the radio undependable because of interference, the navigator of an aircraft, on an over-water flight, decides it would be advisable to take a double drift in order to assure maximum accuracy in his dead reckoning.

Upon gaining the captain's approval to proceed with a double drift, the navigator notes the aircraft's true air speed (170 knots) and the true on-course heading (105°). He then requests the captain to steady the aircraft on a true heading of 150° (which is 45° right of the on-course heading). After the aircraft has flown on this heading long enough to permit the navigator to take a careful drift reading (usually about five minutes), the navigator requests the captain to steer a true heading

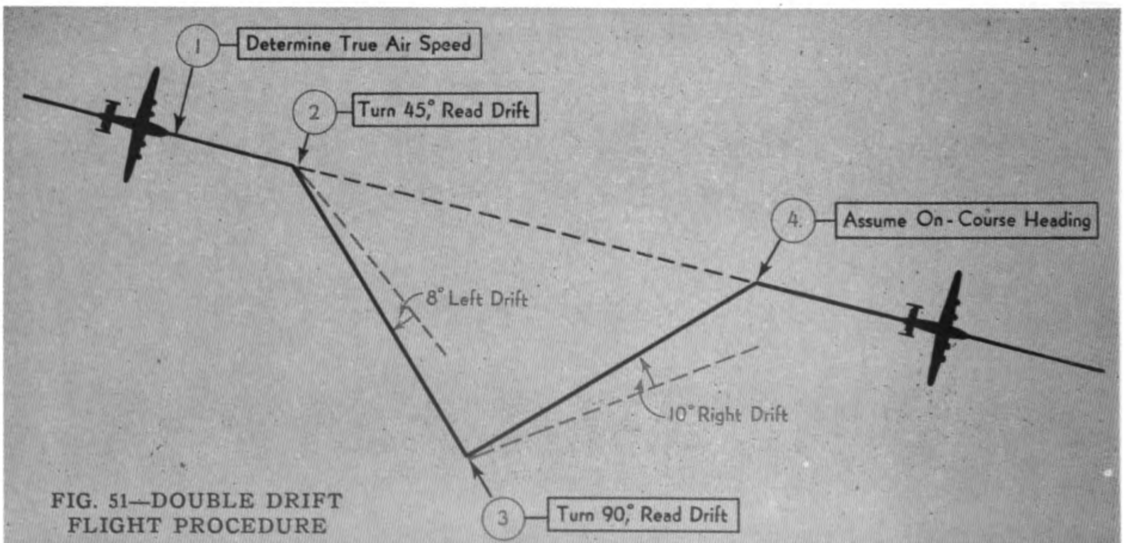


FIG. 51—DOUBLE DRIFT FLIGHT PROCEDURE



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of 60° (which is 45° to the left of the on-course heading). The navigator then takes his second drift reading, and after the aircraft has flown on this second off-course heading for the same number of minutes as were required for the first off-course leg, he advises the captain to return to the on-course heading of 105°.

**Note:** Flying an equal time on each off-course leg will bring the aircraft back to the original track.

**Solution** (Figure 52)

**Given:** On-course true heading 105°
True air speed 170 knots
First true heading 150°
(45° right of on-course heading)
Drift 8° left
Second true heading 60°
(45° left of on-course heading)
Drift 10° right

**Find:** Wind—direction and velocity.

## RADIUS OF ACTION

**Radius of Action** is the distance an aircraft can fly with a given amount of fuel, and under given wind conditions, and still return to its starting base or an alternate base. Radius of action is sometimes called, in ocean navigation, the "point of no return," or "splash point." Once the pilot has flown past this point he cannot safely return, and must reach his destination, or "splash"!

**Safe Return** means to allow sufficient fuel reserve for safe landing and for unforeseen conditions. In long range flying, from San Diego to Honolulu, for example, fuel for two hours flying deducted from the total flying time is considered a safe reserve above available fuel hours. On shorter flights, with proportionately less fuel, 25% usually is kept in reserve.

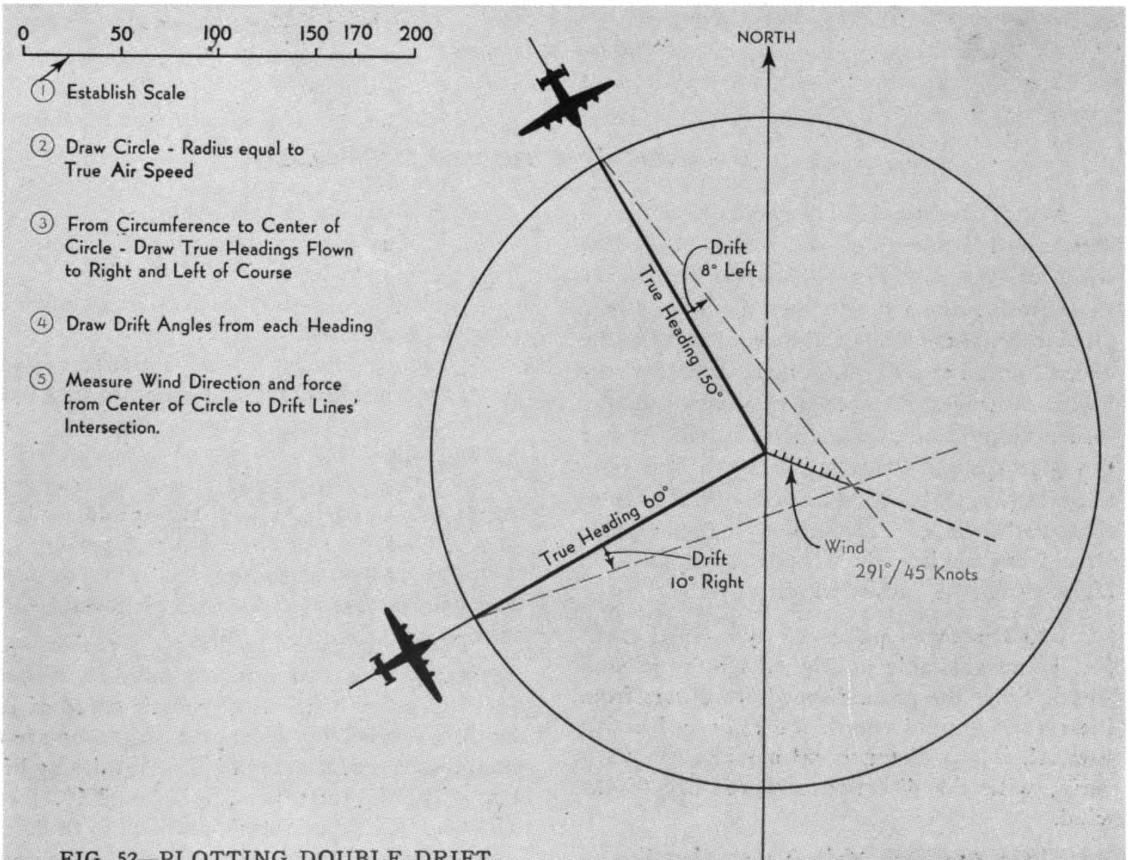


FIG. 52—PLOTTING DOUBLE DRIFT



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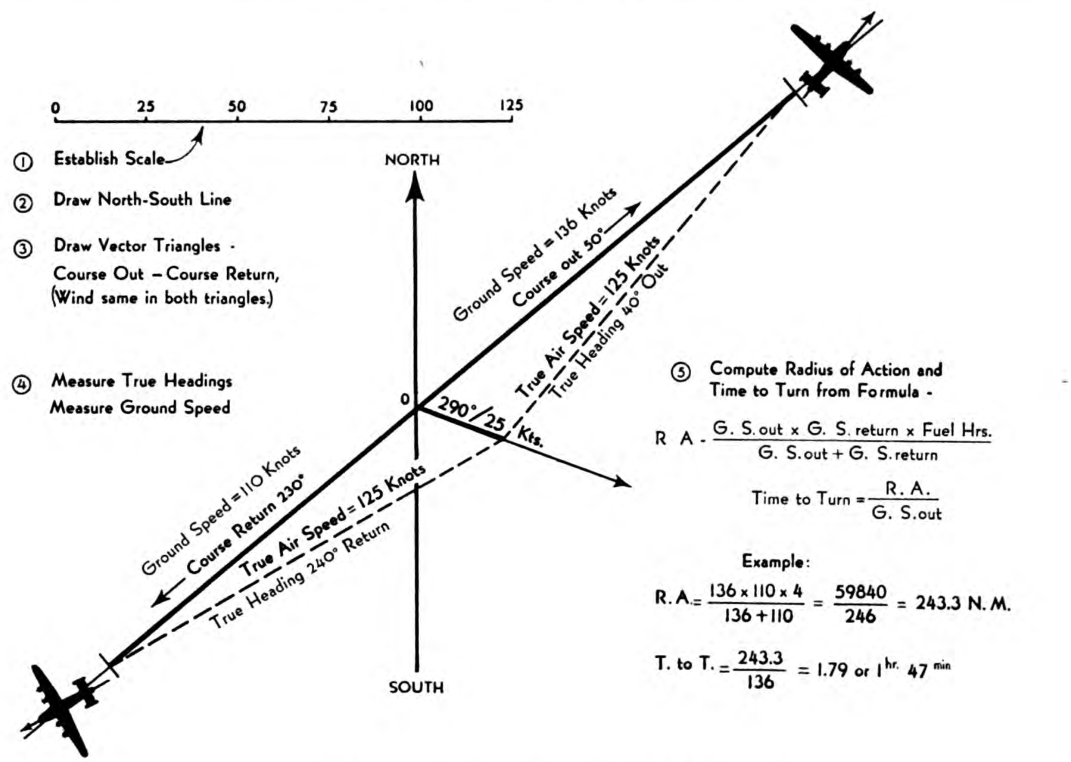


FIG. 53—RADIUS OF ACTION TO SAME BASE

**Wind Conditions**—The radius of action is determined before take-off, using estimated wind, and the wind is considered to remain the same during the trip out and the return trip. Obviously, the force of the wind affects the ground speed and heading on both legs of the flight. However, the change of heading for the return flight results in a different wind vector triangle. Actual winds encountered in a long range flight sometimes differ considerably from estimated winds. Therefore, the navigator should re-calculate the splash point while in flight, using the known wind.

**The Distance** a plane can fly is equal to the fuel hours available multiplied by the ground speed. Since the ground speed out differs from the return ground speed, the radius of action —which is the distance *out* a plane can fly— varies with the direction and velocity of the wind.

**There Are Two Main Types** of radius of action problem:

1. Returning to the same base.
2. Turning off-course to an alternate base.

In both problems the following information is determined:

Distance out (radius of action); time to turn; true heading out and true heading back or to an alternate; ground speed out and ground speed back or to an alternate. The true headings and ground speeds out and back result in two parts in each type problem, both of which may be solved by vector triangles.

The radius of action and time to turn, however, are solved by special formulas.

**Returning to Same Base — Problem —** A navigator of an aircraft containing sufficient fuel to fly five hours at a true air speed of 125 knots is notified by the captain that they are to search on a true course of 50° for a missing lifeboat. The forecast wind is from 290°, force 25 knots. The navigator's problem is to determine how far out his aircraft may search and still return safely with a one-hour fuel reserve.



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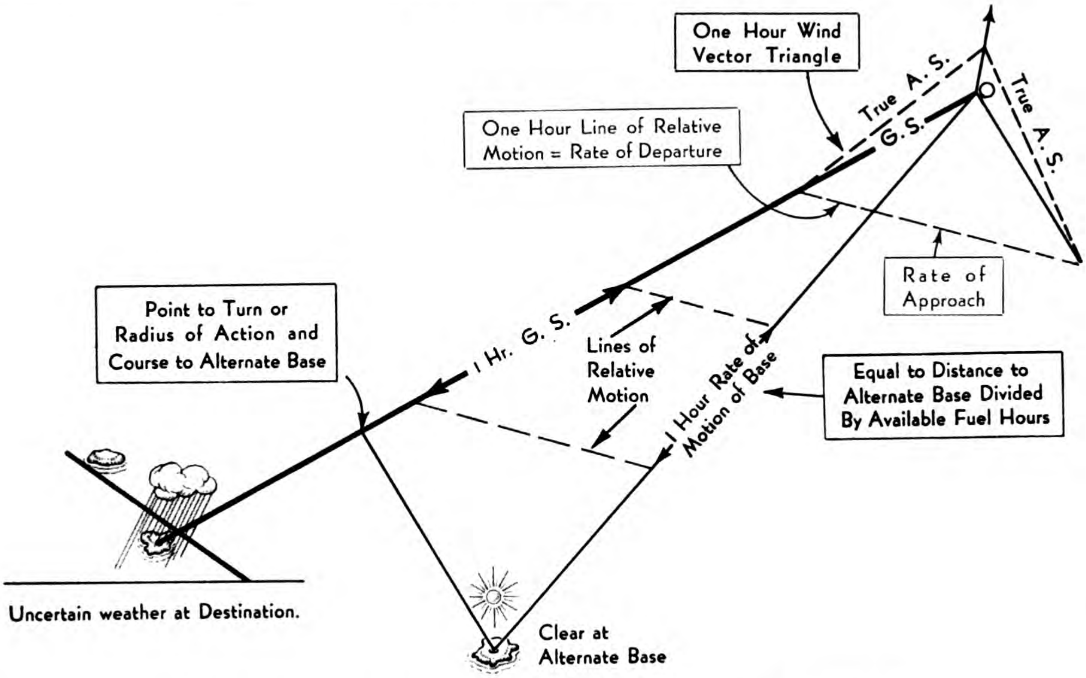


**FIG 54—RADIUS OF ACTION TO ALTERNATE BASE: THEORY**

**Solution** (Figure 53)

**Given:** Course out 50°
Course return 230° (reciprocal)
Fuel available 4 hours (5 hours total, 1 hour reserve)
True air speed 125 knots
Estimated wind 290°/25 knots

**Find:** Distance out (radius of action)
Heading out
Heading return
Time to turn

**Turning To An Alternate Base**—This is primarily a safety problem and is employed to determine how far an aircraft can fly toward a desired destination and still return to an alternate base if necessary.

The problem is based on relative motion of the alternate base, which actually may be a moving base, such as an aircraft carrier, or a fixed base, which for purposes of the problem is considered to move. In either case, the aircraft and the alternate base are assumed to start at the same time, from the same position. Each moves at its respective velocity for the same length of time—an amount equal to the number of available fuel hours—but on different tracks.

Figure 54 illustrates the tracks and relative motion of aircraft and alternate base.

**Problem**—A navigator of an aircraft containing sufficient fuel to fly seven hours at a true air speed of 150 knots leaves his base airport flying on a course of 250° toward a distant island. The forecast wind is from 200°, force 25 knots; however, the weather report shows a warm front approaching, making safe landing at the desired island uncertain. Weather conditions at an alternate island bearing 230° true and 55° nautical miles from his base airport are clear and expected to remain so. Therefore, since it is necessary to reach the distant island if at all possible, the captain decides to proceed, hoping to arrive before the front closes in. The navigator's problem is to determine how far they can proceed toward the desired island and still, if advised by radio it will be impossible to land, to turn off and reach the alternate island with a safe one and one-half hours of fuel in reserve.



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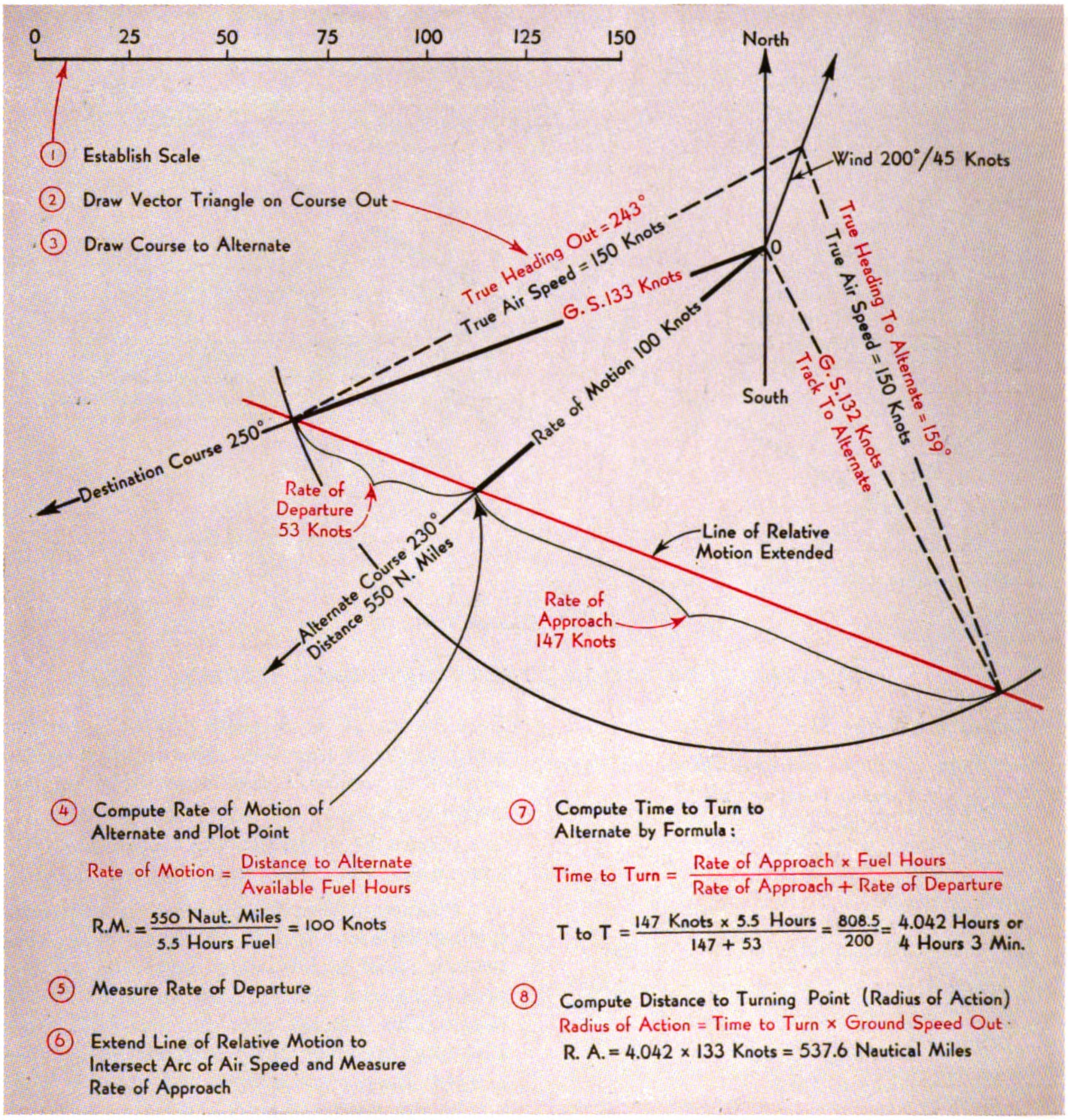


**FIG. 55—RADIUS OF ACTION TO ALTERNATE BASE: EXAMPLE**

**Solution** (Figure 55)

**Given:** Course to destination 250°
Course to alternate 230°
Distance to alternate 550 nautical miles
Fuel available 5½ hrs. (7 total) (1½ reserve)
True air speed 150 knots
Estimated wind 200°/25 knots

**Find:** True heading out
True heading to alternate
Time to turn
Distance to turning point



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**PROBLEM WORK NO. 6**

**APPLYING COMPASS ERRORS**

(Find missing values.)

| No. | TRUE COURSE | VARIATION | MAGNETIC COURSE | DEVIATION | COMPASS COURSE |
|---|---|---|---|---|---|
| 1 | 92° | | 82° | 2°E | |
| 2 | | 14°E | 256° | | 259° |
| 3 | 30° | 6°E | | 1°E | |
| 4 | | 16°E | 346° | 0° | |
| 5 | 165° | | 170° | | 175° |
| 6 | 332° | 11°W | | | 339° |
| 7 | 122° | | | 3°W | 125° |
| 8 | | 13°E | | 2°E | 344° |
| 9 | 1° | | 11° | | 10° |
| 10 | 115° | | | 4°E | 96° |
| 11 | | 14°W | | 3°E | 234° |
| 12 | 225° | | 216° | 3°W | |
| 13 | | 3°W | 150° | 4°W | |
| 14 | 118° | | 129° | | 120° |
| 15 | 322° | 7°E | | | 320° |
| 16 | 187° | 14°W | | 1°E | |
| 17 | | 16°E | 296° | | 302° |
| 18 | 334° | | | 4°W | 330° |
| 19 | | 14°E | 349° | 6°E | |
| 20 | 96° | | 101° | 1°E | |



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**PROBLEM WORK NO. 7**

**TRACK AND HEADING**

(Find missing values.)

| No. | Track True | Var. | Track Magnetic | Drift | Heading Magnetic | Dev. | Heading | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Compass | True |
| 1 | 117° | 14°E | | 2°R | | 3°W | | |
| 2 | | 16°W | 247° | | 243° | | 241° | |
| 3 | 47° | | 61° | | | 3°W | | 51° |
| 4 | 342° | | 332° | | 326° | | 326° | |
| 5 | 96° | 15°E | | | 78° | | 71° | |
| 6 | | 16°W | 292° | | 290° | | 299° | |
| 7 | 111° | 10°W | | | | 4°W | | 110° |
| 8 | | 14°E | 228° | | 226° | 3°E | | |
| 9 | 167° | | 151° | 4°L | | | 161° | |
| 10 | | 12°W | | 0° | 221° | | 217° | |
| 11 | | 10°W | | 2°L | 185° | 0° | | |
| 12 | | | 182° | | 178° | | 183° | 194° |
| 13 | | 17°W | | 7°R | | | 120° | 107° |
| 14 | 356° | | 345° | | | 2°E | 344° | |
| 15 | 6° | | 352° | | 353° | 10°W | | |
| 16 | | 16°E | 284° | 3°R | | | 275° | |
| 17 | 249° | | 261° | 1°L | | 14°W | | |
| 18 | | 14°W | | 4°R | | 5°W | | 218° |
| 19 | | | | 4°L | 180° | 10°W | | 204° |
| 20 | | 18°E | 100° | | 96° | | 90° | |



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**PROBLEM WORK NO. 8**

**TIME—SPEED—DISTANCE**

(Find missing values. Use computer only for checking work.)

| No. | TIME | SPEED (Knots) | DISTANCE (Nautical Miles) |
|---|---|---|---|
| 1 | $1^h27^m$ | 125 | |
| 2 | $1^h34^m$ | 136 | |
| 3 | $2^h02^m$ | 171 | |
| 4 | $0^h44^m$ | 152 | |
| 5 | $4^h13^m$ | 111 | |
| 6 | $2^h16^m$ | 106 | |
| 7 | $3^h57^m$ | 72 | |
| 8 | $0^h52^m$ | 176 | |
| 9 | $2^h02^m$ | | 240 |
| 10 | $1^h16^m$ | | 200 |
| 11 | $6^h26^m$ | | 702 |
| 12 | $3^h21^m$ | | 476 |
| 13 | $2^h14^m$ | | 317 |
| 14 | $0^h56^m$ | | 173 |
| 15 | $4^h03^m$ | | 600 |
| 16 | | 168 | 240 |
| 17 | | 160 | 310 |
| 18 | | 201 | 117 |
| 19 | | 117 | 156 |
| 20 | | 115 | 196 |



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## PROBLEM WORK NO. 9-A
## VECTOR DIAGRAMS

(Draw vector triangles to find: Heading—ground speed—drift. All velocities in knots.)

| No. | True Course | I.A.S. | Calibration Correction | C.A.S. | T.A.S. | Pressure Altitude | Temp. C° | WIND Dir. | WIND Vel. | Var. | Dev. | HEADING True | HEADING Compass | Ground Speed | Drift |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 85° | | | | 90 | | | 320° | 30 | | | | | | |
| 2 | 173° | | | | 110 | | | 84° | 40 | | | | | | |
| 3 | 140° | | | | 95 | | | 230° | 25 | | | | | | |
| 4 | 300° | | | | 120 | | | 53° | 35 | | | | | | |
| 5 | 208° | | | | 140 | | | 304° | 20 | | | | | | |
| 6 | 148° | | | 177 | | 5000′ | +15° | 223° | 50 | | | | | | |
| 7 | 170° | | | 152 | | 10,000′ | +10° | 90° | 25 | | | | | | |
| 8 | 240° | | | 124 | | 6000′ | — 5° | 308° | 20 | | | | | | |
| 9 | 37° | | | 108 | | 25,000′ | — 3° | 117° | 25 | | | | | | |
| 10 | 0° | | | 170 | | 4000′ | +12° | 270° | 40 | | | | | | |
| 11 | 350° | 140 | +8 | | | 14,000′ | —30° | 48° | 34 | | | | | | |
| 12 | 16° | 150 | +4 | | | 10,000′ | +15° | 131° | 29 | | | | | | |
| 13 | 100° | 98 | —3 | | | 20,000′ | — 5° | 355° | 18 | | | | | | |
| 14 | 60° | 110 | —4 | | | 16,000′ | — 5° | 142° | 28 | | | | | | |
| 15 | 330° | 129 | +6 | | | 8000′ | +20° | 79° | 16 | | | | | | |
| 16 | 204° | 125 | —5 | | | 4500′ | +25° | 85° | 24 | 2°E | 1°E | | | | |
| 17 | 31° | 138 | —2 | | | 3000′ | +30° | 286° | 19 | 5°W | 3°E | | | | |
| 18 | 76° | 170 | —1 | | | 5500′ | —10° | 138° | 21 | 7°E | 12°W | | | | |
| 19 | 190° | 124 | +2 | | | 7000′ | +12° | 251° | 25 | 2°W | 16°E | | | | |
| 20 | 270° | 102 | +3 | | | 6500′ | +15° | 49° | 32 | 11°E | 17°W | | | | |



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## PROBLEM WORK NO. 9-B

## VECTOR DIAGRAMS

(Draw vector triangles to find wind and drift.)

| No. | True Course | Ground Speed (knots) | HEADING | | Dev. | Var. | I.A.S. (m.p.h.) | Calibration Correction | C.A.S. (knots) | T.A.S. (knots) | Pressure Altitude | Temp. C° | WIND | | Drift |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Compass | True | | | | | | | | | Dir. | Vel. (kts) | |
| 1 | 85° | 130 | | 75° | | | | | | 144 | | | | | |
| 2 | 145° | 93 | | 120° | | | | | | 110 | | | | | |
| 3 | 290° | 110 | | 280° | | | | | | 128 | | | | | |
| 4 | 194° | 121 | | 206° | | | | | | 118 | | | | | |
| 5 | 30° | 101 | | 44° | | | | | | 106 | | | | | |
| 6 | 48° | 138 | 53° | | 2°W | 4°E | | | | 145 | | | | | |
| 7 | 95° | 119 | 87° | | 7°E | 5°W | | | | 115 | | | | | |
| 8 | 210° | 162 | 218° | | 3°E | 2°W | | | | 128 | | | | | |
| 9 | 176° | 178 | 176° | | 2°E | 15°W | | | | 162 | | | | | |
| 10 | 300° | 147 | 277° | | 4°E | 3°E | | | | 144 | | | | | |
| 11 | 275° | 109 | 290° | | 6°W | 1°W | | | 103 | | 3000′ | —10° | | | |
| 12 | 60° | 157 | 67° | | 2°W | 6°E | | | 153 | | 2500′ | — 5° | | | |
| 13 | 118° | 143 | 94° | | 10°E | 2°E | | | 116 | | 1900′ | — 7° | | | |
| 14 | 4° | 99 | 347° | | 12°E | 2°W | | | 76 | | 20,000′ | + 3° | | | |
| 15 | 17° | 111 | 37° | | 2°W | 0° | | | 76 | | 11,500′ | +18° | | | |
| 16 | 150° | 141 | 155° | | 2°W | 15°W | 130 | —6 | | | 7000′ | +22° | | | |
| 17 | 10° | 126 | 12° | | 8°E | 12°E | 139 | +7 | | | 6500′ | — 4° | | | |
| 18 | 138° | 101 | 145° | | 3°E | 1°E | 105 | —4 | | | 2000′ | +10° | | | |
| 19 | 141° | 117 | 141° | | 11°E | 7°W | 142 | —6 | | | 3500′ | —10° | | | |
| 20 | 101° | 129 | 101° | | 2°E | 14°W | 136 | +2 | | | 1000′ | —13° | | | |



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**PROBLEM WORK NO. 10**

**DOUBLE DRIFT**

(Find wind by drawing "wind stars." All velocities in knots.)

| No. | T.A.S. | FIRST HEADING | DRIFT | SECOND HEADING | DRIFT | WIND DIRECTION | WIND VELOCITY |
|---|---|---|---|---|---|---|---|
| 1 | 90 | 258° | 7°R | 348° | 0° | | |
| 2 | 120 | 220° | 10°L | 130° | 1°R | | |
| 3 | 160 | 260° | 6°R | 170° | 1°R | | |
| 4 | 160 | 0° | 13°L | 90° | 4°L | | |
| 5 | 150 | 270° | 4°R | 180° | 8°R | | |
| 6 | 130 | 315° | 11°L | 15° | 6°L | | |
| 7 | 110 | 0° | 0° | 270° | 10°R | | |
| 8 | 175 | 90° | 8°L | 180° | 2°L | | |
| 9 | 165 | 45° | 5°R | 135° | 10°R | | |
| 10 | 145 | 55° | 10°R | 145° | 2°R | | |
| 11 | 155 | 75° | 5°R | 345° | 5°R | | |
| 12 | 160 | 85° | 5°R | 175° | 0° | | |
| 13 | 180 | 120° | 13°L | 30° | 5°L | | |
| 14 | 135 | 140° | 5°R | 230° | 8°R | | |
| 15 | 150 | 160° | 8°L | 70° | 2°L | | |
| 16 | 170 | 180° | 5°R | 80° | 6°R | | |
| 17 | 130 | 190° | 7°R | 280° | 3°R | | |
| 18 | 185 | 200° | 10°L | 110° | 6°L | | |
| 19 | 140 | 240° | 7°R | 150° | 2°R | | |
| 20 | 120 | 220° | 10°R | 310° | 4°R | | |



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## PROBLEM WORK NO. 11-A

## RADIUS OF ACTION TO A FIXED BASE

(Draw vector diagrams and find missing values.)

| No. | True Course Out | Wind (knots) | C.A.S. (knots) | Temp. C° | Pressure Altitude | T.A.S. (knots) | Fuel Hours | Fuel Reserve | Fuel Available | GCT Take-off Time | True Heading Out | True Heading In | Radius of Action | Time to Turn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 82° | 50°/30 | 182 | + 2° | 6000′ | | 6 | 10% | | 09:30 | | | | |
| 2 | 310° | 250°/30 | 160 | — 3° | 4000′ | | 4 | 8% | | 10:20 | | | | |
| 3 | 198° | 280°/30 | 200 | — 5° | 5000′ | | 3 | 30m | | 14:20 | | | | |
| 4 | 250° | 280°/30 | 140 | — 4° | 10,000′ | | 10 | 5% | | 16:30 | | | | |
| 5 | 270° | 30°/24 | 125 | +10° | 3000′ | | 4 | 10% | | 10:30 | | | | |
| 6 | 200° | 90°/36 | 111 | —20° | 8000′ | | 4:30 | 30m | | 07:10 | | | | |
| 7 | 50° | 270°/10 | 110 | +10° | 9000′ | | 9 | 1h | | 06:40 | | | | |
| 8 | 40° | 300°/30 | 90 | —10° | 5000′ | | 5 | — | | 15:15 | | | | |
| 9 | 20° | 270°/70 | 130 | —20° | 10,000′ | | 8 | 25% | | 01:24 | | | | |
| 10 | 135° | 70°/44 | 175 | 0° | 3000′ | | 7 | 15% | | 00:45 | | | | |



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## PROBLEM WORK NO. 11-B

## RADIUS OF ACTION TO ALTERNATE BASE

(Draw vector diagrams and find missing values.)

| No. | TRUE COURSE TO | | Distance to Alternate (Nautical Miles) | Wind | T.A.S. (knots) | Fuel Hours | Fuel Reserve | Fuel Available | TRUE HEADING TO | | Distance Out | Time to Turn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Destination | Alternate | | | | | | | Destination | Alternate | | |
| 1 | 50° | 76° | 280 | 270°/30 | 90 | 4 | — | | | | | |
| 2 | 240° | 170° | 180 | 180°/32 | 90 | 4 | 10% | | | | | |
| 3 | 30° | 340° | 180 | 170°/20 | 80 | 5 | 10% | | | | | |
| 4 | 270° | 230° | 245 | 45°/30 | 120 | 3.5 | — | | | | | |
| 5 | 130° | 180° | 200 | 210°/30 | 200 | 5 | — | | | | | |
| 6 | 350° | 250° | 180 | 270°/31 | 110 | 5 | 30 min. | | | | | |
| 7 | 20° | 190° | 225 | 80°/60 | 100 | 6 | 20% | | | | | |
| 8 | 110° | 360° | 600 | 220°/40 | 160 | 5 | — | | | | | |
| 9 | 190° | 245° | 300 | 30°/30 | 140 | 3 | 30 min. | | | | | |
| 10 | 290° | 200° | 360 | 340°/15 | 110 | 4 | 10% | | | | | |



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## DEAD RECKONING REVIEW TEST

1. Define:

   (a) Latitude
   (b) Longitude
   (c) Great Circle
   (d) Variation
   (e) Rhumb Line

2. Draw diagrams showing the projection and development of the Mercator, Lambert, and gnomonic charts, and list advantages and disadvantages of each.

3. Show how rhumb line track and great circle track appear on gnomonic chart and also on Mercator chart.

4. (a) Compass course is 302°, variation 10°W, deviation 4° E. What is magnetic course? What is true course?

   (b) True heading is 210°, variation 16°E, drift 4° left, deviation 3°W. What is true track? Compass heading? Magnetic track?

   (c) True course is 33°, variation 12°E, deviation 6°E, drift 4° right. What is true heading? Compass course? Magnetic course?

5. Pressure altitude is 8000 ft., indicated altitude 9000 ft., temperature +8°C. What is true altitude?

6. (a) Indicated air speed is 179 m.p.h., instrument correction +2 m.p.h., altitude 10,000 ft., temperature +10°C. What is calibrated air speed in knots? True air speed in knots?

   (b) Calibrated air speed is 157 knots, altitude 12,000 ft., temperature 0°C. What is true air speed in knots?

7. San Diego to position "A" is 510 nautical miles. Aircraft's true air speed is 180 knots, wind directly astern at 19 knots, time of departure is 03:10 GCT.

   (a) At what time will plane reach position "A"?

   (b) If aircraft arrives at position "A" at 07:30 GCT, what is the ground speed?

   (c) If ground speed is 115 knots and aircraft arrives at position "A" at 09:10 GCT, what is the distance to position "A"?

8. (a) True air speed is 150 knots, wind 30°/30 knots, course 272°. What will be the estimated ground speed? True heading? Drift?

   (b) True heading is 60°, true air speed 100 knots, wind 350°/25 knots. What will be the estimated ground speed? Track? Drift?

   (c) Track is 195°, true heading 210°, true air speed 190 knots, ground speed 210 knots. What is wind? Drift?

9. While on a true heading of 230°, true air speed 120 knots, a navigator decides to take a double drift to determine the wind. His first true heading is 275°, drift 8° right. His second true heading is 185°, drift 10° left. What is direction and force of wind?

10. With 6 hours of fuel available over the required reserve, how far can an aircraft fly on true course of 220°, at a true air speed of 180 knots, wind 300°/33 knots and still return to its starting point? If the aircraft leaves San Diego at 09:15 GCT, what time should it turn around?



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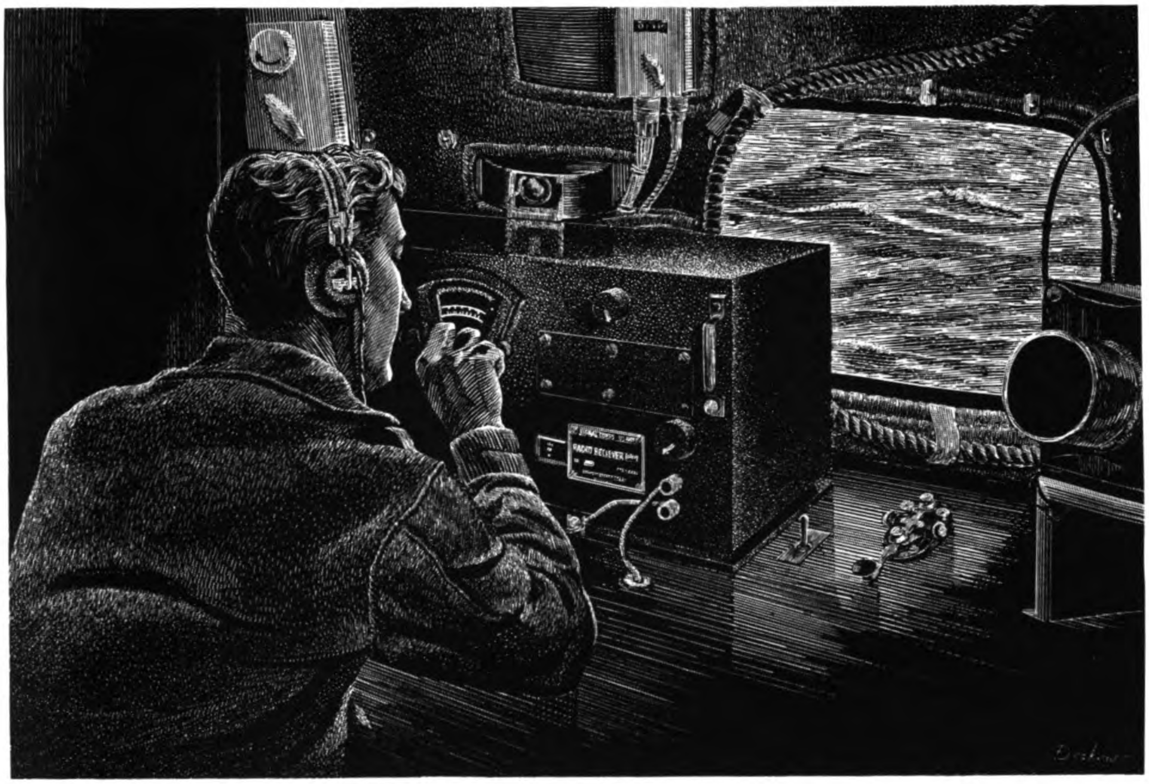


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# RADIO NAVIGATION

RADIO navigation is the method of determining an aircraft's position with relation to, or its direction from, known radio transmitting stations. To accomplish this orientation, advantage is taken of the directional characteristics of a loop antenna. However, because of interferences affecting transmission, and due to design limitations of present-day radio equipment, plus the fact that reception and use of radio waves are limited to the skill of the operator, radio navigation is not as accurate as celestial navigation or pilotage. Hence it should be used only as an *aid to navigation* in conjunction with all other available methods.

**Radio Wave Characteristics**—The radio bearing between a ground station and an aircraft is a direct line over the surface of the earth; hence, it follows a great circle track (Figure 56). Drawn on a Mercator chart, the bearing would appear as a curved line bending toward the elevated pole (Figure 57).

The path of a radio wave, however, often is refracted, reflected, or otherwise caused to deviate from a great circle track by storms, by mountains, by passage over a coastline or by the phenomenon known as "night effect." *Night effect* is the change in reflection of the radio wave from the ionosphere, and is always encountered; however, the effect is more pronounced at sunrise and sunset (hence "night effect"), and may be recognized by a fluctuation in bearings. Night effect may be reduced



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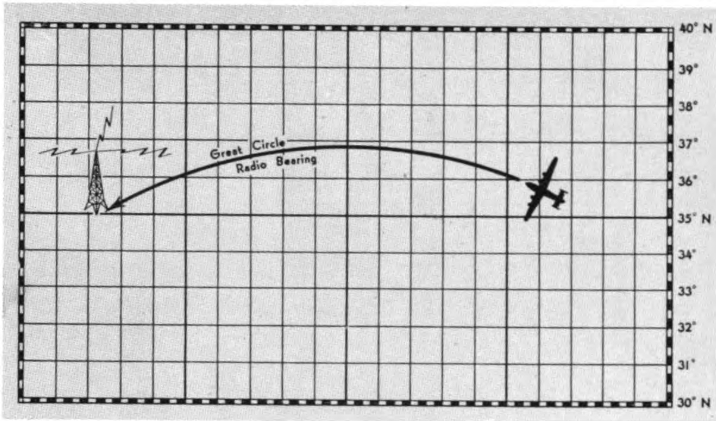


FIG. 57—RADIO BEARING APPEARS AS CURVED LINE ON MERCATOR CHART

somewhat by varying the altitude of the aircraft, by taking an average of the fluctuations, or by selecting a station of lower frequency.

**Value of Radio**—Even with present-day limitations and the difficulties inherent in wave transmission, radio is an invaluable aid to navigation. With the development of better equipment and the continual increase in the number of ground stations throughout the world, it will continue to assume more importance.

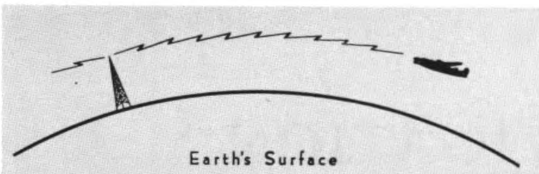


FIG. 56—RADIO BEARING FOLLOWS GREAT CIRCLE PATH

With radio, an aircraft can remain in constant communication with the ground as well as with other aircraft. By means of the radio direction finder (radio compass), bearings may be taken of a transmitting station, either on the ground or in another aircraft, with which the navigator can establish his position with relation to the transmitting station. By means of radio range stations, an aircraft's position can be determined so accurately that landings may be made even without visual contact with the ground.

## RADIO COMPASS

**Description**—The radio compass is an instrument for receiving radio wave signals and measuring the *relative bearing* of the transmitting station from the aircraft's heading. The

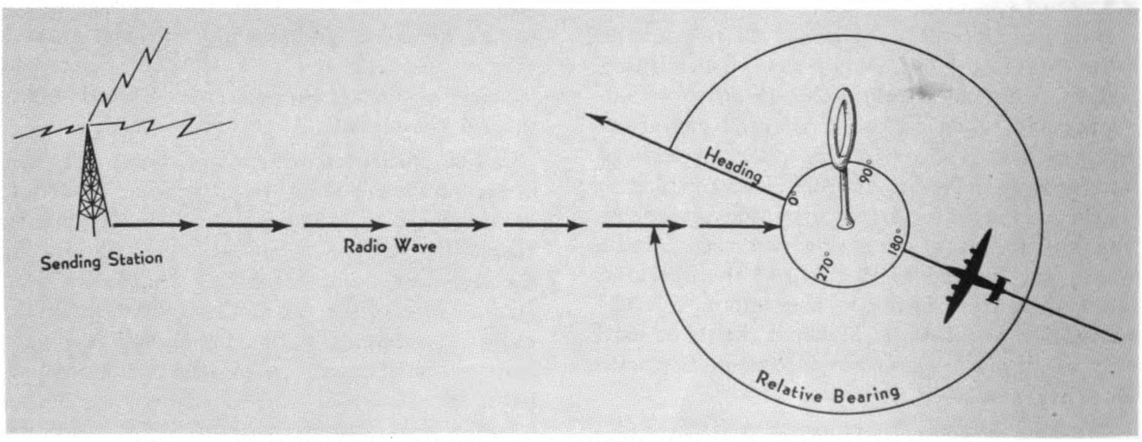


FIG. 58—ESTABLISHING RELATIVE BEARING WITH ROTATABLE LOOP



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principle of operation involves the directional characteristics of a *loop antenna.* When the loop is at *right angles* to the direction of incoming radio waves, minimum signal volume is heard; maximum volume is heard when the loop is *parallel* to the incoming signal waves (Figure 58).

By use of the radio compass, direction of the transmitting station is established on an azimuth ring (Figure 59) by a pointer actuated by a rotatable loop antenna. The azimuth ring is graduated in a clockwise direction from 0° to 360°, the 0° and 180° points being aligned with the longitudinal axis of the aircraft. When the pointer is at 0°, the loop is at right angles to the longitudinal axis.

When the loop antenna is swung back and forth until the mean point of minimum volume is established, the azimuth dial then indicates the relative bearing of the transmitting station from the aircraft's heading. The point of minimum volume is used because, due to the antenna loop characteristics, that point is easier to detect than the point of maximum volume.

Loop antennas may be either manually or automatically operated.

**Manually Operated Loop**—The loop is rotated by a hand-operated crank. When the station signal received is at a minimum volume, the loop is at right angles to the radio wave received, indicating the *station's relative bearing.*


Courtesy Bendix Radio Division, Bendix Aviation Corporation

**FIG. 59—AZIMUTH DIAL**


Courtesy Bendix Radio Division, Bendix Aviation Corporation

**FIG. 60—CONTROL PANEL**

**Automatically Operated Loop**—When the station is correctly tuned in, an electric motor automatically rotates the loop, keeping it at right angles to the station from which the radio wave is emanating.

**Note:** If the crank mechanism or motor fails, it is possible in some installations to rotate the loop by hand. In such a case, the loop should be turned perpendicular to the aircraft's longitudinal axis. With the loop in this position, the aircraft can be pointed toward the transmitting station by altering the heading until the signal wave is at minimum volume. The bearing of the transmitting station is then indicated on the magnetic compass, relative to compass North.

## BENDIX RADIO COMPASS

The following is the general procedure for operating the Bendix radio compass equipment as it is used by the ocean aerial navigator for homing to a required destination, for taking bearings, and for fixing the aircraft's position. Other installations are similar, and procedures are practically the same.

**Master Switch**—The master switch on the control panel (Figure 60) has four contacts: OFF, COMP (Compass), REC ANT (Receive Antenna), REC LOOP (Receive Loop), which



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control all radio compass functions other than tuning and adjustment of signal levels, as follows:

1. OFF—No current is going through the set.

2. COMP—The equipment functions as a direction finding receiver connected to the loop and sense antenna, operating the *left-right indicator.*

3. REC ANT — The equipment is connected to the non-directional vertical antenna. As such, it is used for aural radio range reception and for obtaining communication reception.

4. REC LOOP—The equipment functions as a communication receiver connected to the directional loop antenna. This contact is used for aural-null bearings, aural-null homing, and for obtaining communication reception or listening to radio range reception during conditions of severe static caused by rain or snow.

**Left-Right Indicator** (Figure 61) — The left-right indicator is an instrument having a pointer in the form of a small conventionalized figure of an airplane which visually indicates "null" radio bearings. The pointer is actuated by the phase relationship of incoming radio waves. Minimum volume causes the pointer to remain at the center of the instrument, thus indicating that the loop antenna is at right angles to the incoming radio wave. When the transmitting station is ahead, rotation of the azimuth dial or changes in aircraft's heading in one direction, will cause the left-right pointer to move in the opposite direction. If the pointer moves in the same direction, the station lies behind the aircraft.


Courtesy Bendix Radio Division, Bendix Aviation Corporation

**FIG. 61—LEFT - RIGHT INDICATOR**

**Preliminary Operation**

a. Turn the *master switch* on.

b. Carefully tune the receiver to the frequency of the desired radio station and adjust the *audio control volume.*

c. Listen to the station's *call sign,* or *identification signal,* in order to make certain that the correct station has been tuned in.

## HOMING

**Procedure**

1. FOR VISUAL HOMING (using left-right indicator).

a. Adjust *master switch* to COMP.

b. Set azimuth dial to read *zero.* The *needle* of the *left-right indicator* now points in the general direction of the transmitting station.

c. Alter the heading of the aircraft to right or left so that the *indicator needle* is centered. The aircraft now will be pointing toward the desired station.

d. If the needle is being continuously deflected right and left of the center, reduce the *compass control volume,* permitting the course to be followed more accurately.

2. FOR AURAL-NULL HOMING (using headphone)—This method of homing is used if the left-right indicator fails, or in case of severe rain static. It is called "flying a null course," and is identical with the method used in visual left-right homing, the only difference being that with this method an audible signal is received via the headphones, and the pilot alters the aircraft's heading to right or left to maintain the signal volume at a minimum.

If the signals are weak, turn the **CW** switch on.

**Note:** Homing is the easiest method of approaching a station on course. However, it should be used only when the aircraft is less than one hundred miles from the station. At greater distances, it would be more practical to plot radio compass bearings and establish compass headings to fly. This is true primarily



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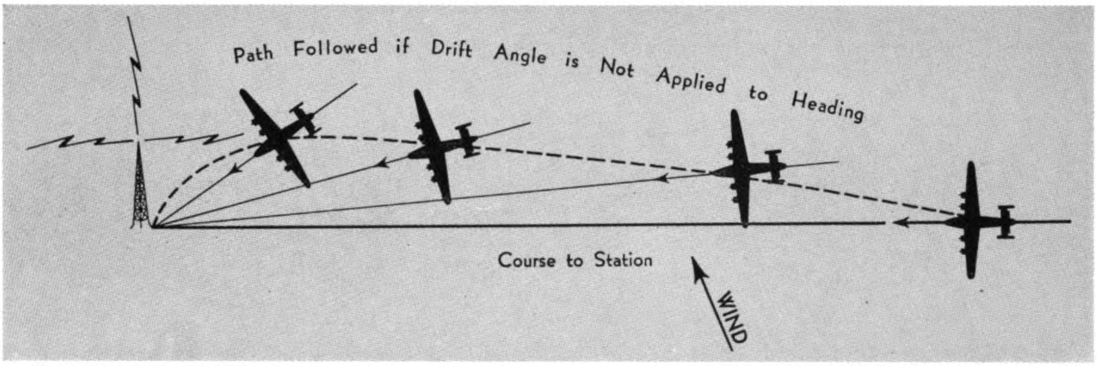


FIG. 62—EFFECT OF WIND IN HOMING

because of the effect of crosswind on the aircraft, for when homing with a strong beam wind blowing, the aircraft's heading has to be altered continuously into the wind in order to keep on the null course, or to keep the needle of the left-right indicator centered. Figure 62 illustrates the effect of wind in homing.

## RELATIVE RADIO BEARINGS

**Definition**—A *relative radio bearing* is the angular direction of the transmitting station measured clockwise from the *true heading of the aircraft.*

**Calibration Error**—Practically all aircraft radio compass installations give definite errors in relative bearings. This error is called *calibration error and must be applied to all relative radio bearings in order to find the correct relative bearing.*

Calibration error is a result of the effect which the metallic fore and aft mass of the fuselage structure, athwartship mass of the wing structure, and other metallic masses in the aircraft have on the rotatable loop antenna. It is determined by a method similar to that used to find compass error, namely, by swinging the aircraft on a compass rose, or in the air, and recording the error found on each 15° heading throughout 360°. The 0° bearing, however, is obtained by heading the aircraft toward the transmitting station and taking the bearing over the nose of the ship. *Hence the 0° point on the azimuth ring indicates the nose of the aircraft and not geographical North, as is the case with the magnetic compass.*

From the data thus obtained, a calibration graph is drawn showing the amount of correction to be applied to any relative bearing.

**Procedure**

1. FOR VISUAL RELATIVE RADIO BEARING (using left-right indicator).

a. Adjust *master switch* to COMP.

b. Rotate *loop* until *needle* of left-right indicator is centered.

c. Read *relative bearing* on the *azimuth dial* and apply *calibration error* to obtain *correct relative bearing.*

2. FOR AURAL-NULL RELATIVE BEARINGS (using headphones).

a. Adjust *master switch* to position of REC LOOP.

b. Rotate *loop* until the headphone volume decreases to a minimum.

c. Read *relative bearing* on the azimuth dial and apply calibration error to obtain *correct relative bearing.*

**True Bearings**—In converting relative bearing to true geographical bearing, employ the following procedure:

a. Note the *compass heading* of the aircraft at the *instant the relative bearing is read.*

b. Convert *compass heading* to *true heading* by applying *variation* and *deviation.*

c. *Add correct relative bearing and true heading.* Since true heading is the direction of the aircraft's heading from true North and the relative radio bearing is the direction of the transmitting station from the aircraft's heading, the sum equals the true geographical great circle bearing of the transmitting station from the aircraft.



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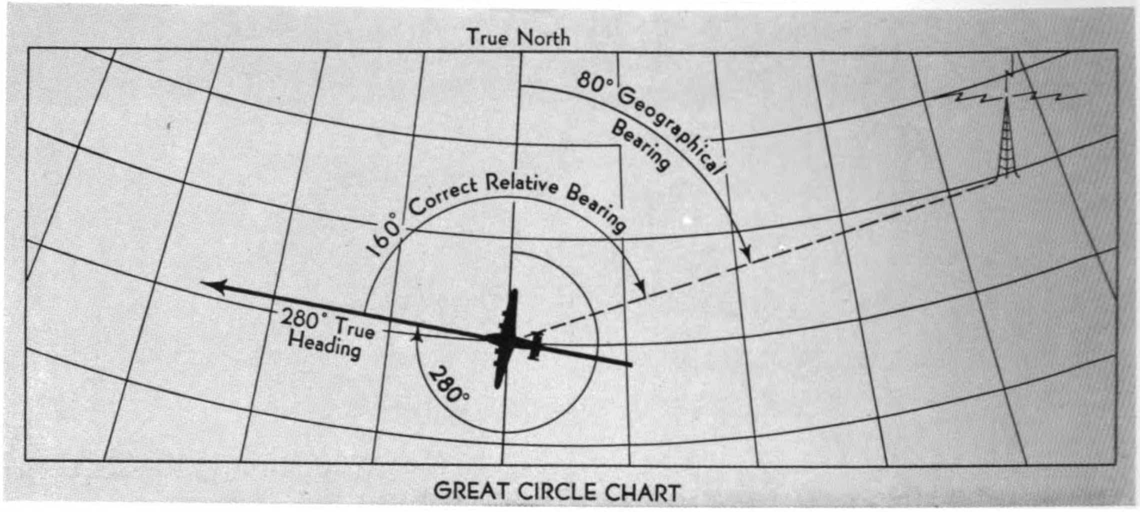


FIG. 63—DETERMINING GREAT CIRCLE BEARING

**Note:** If the sum of the relative bearing and true heading is over 360°, subtract 360°.

*Example* (Figure 63)

| | | |
|---|---|---|
| Compass heading | = | 265° |
| Deviation | = | 5°E |
| Magnetic heading | = | 270° |
| Variation | = | 10°E |
| True heading | = | 280° |
| Relative radio bearing | = | 155° |
| Calibration correction | = | +5° |
| Correct relative bearing | = | 160° |
| True heading | = | 280° |
| Sum | = | 440° |
| Less 360° | | —360° |
| Great circle bearing | = | 80° |
| Mercator correction | = | +2° |
| Rhumb line bearing | = | 82° |

**Mercator Correction** — Since radio waves follow a great circle path which, on the Mercator chart appears as a curved line bending toward the elevated pole, a correction has to be applied to all radio bearings before they can be plotted as straight lines (rhumb lines) on the Mercator chart (Figure 65).

**Correction Amount**—The amount of correction to be applied in order to convert the great circle bearing into a rhumb line bearing varies with the *mid-latitude*, and the *difference of longitude* between the aircraft and the transmitting station. This correction is gained by inspection of a radio bearing conversion table (Figure 64). The table should be part of the navigator's equipment and is in either tabular or graphic form.

**Correction Sign**—The *sign* of the correction is either *plus* or *minus* depending upon the position of the receiver with relation to the transmitting station. The sign of the correction for any position may be determined as shown in Figure 66. Thus, in Figure 64 or 66, when the receiver is West of the transmitting station (North latitude), the great circle bear-

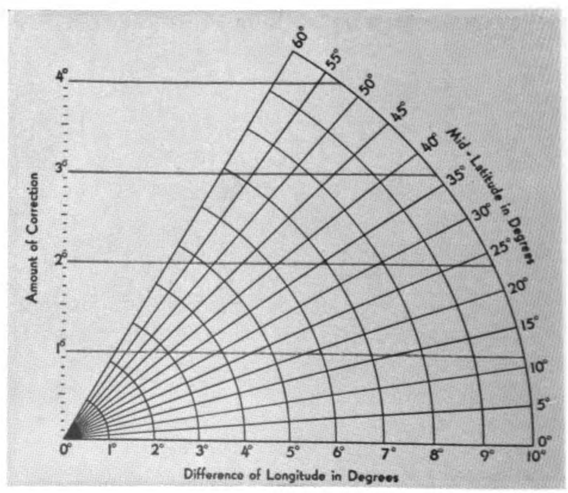


FIG. 64—MERCATOR CORRECTION DIAGRAM



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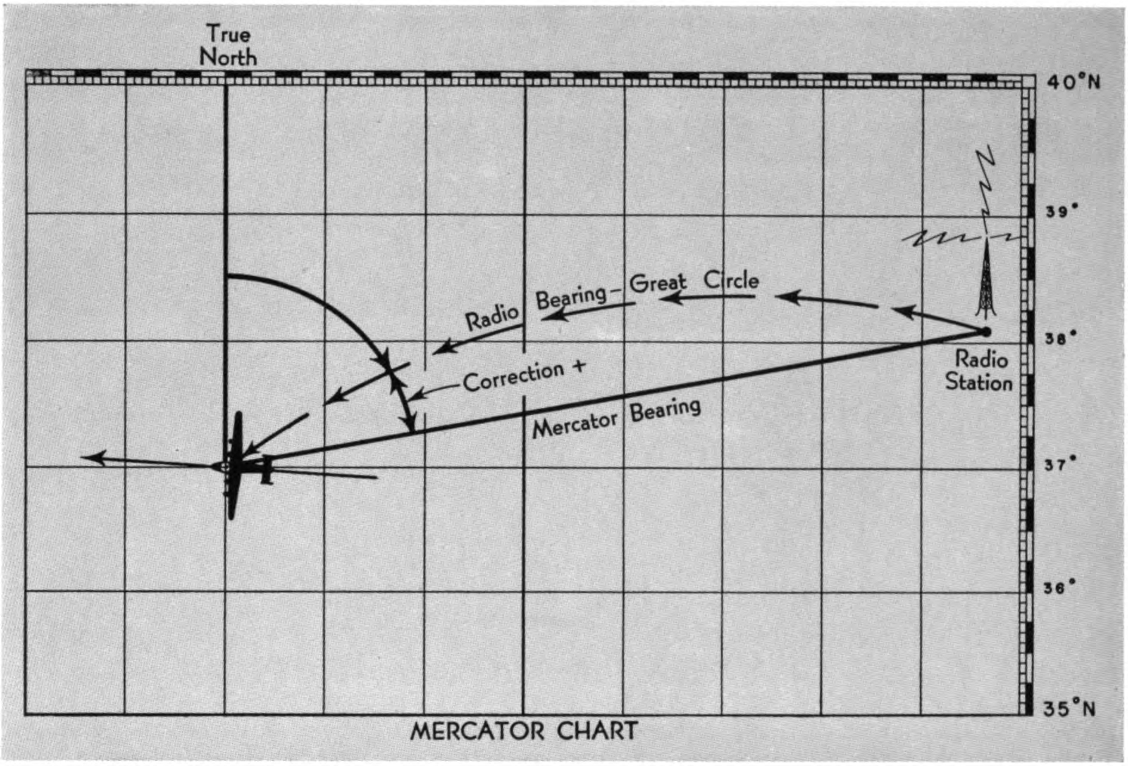


FIG. 65—CONVERTING GREAT CIRCLE BEARING TO MERCATOR BEARING

ing, which bends toward the poles, is less than the rhumb line bearing. Therefore, the correction is plus. In South latitude, the correction would be minus because the great circle there bends toward the South pole.

## RADIO RANGES

**Description**—Radio range beacons are the safest and most widely-used form of directional guidance in the United States. Hundreds of radio range beacons mark every airway commercially flown in this country, and now, with the establishment of island air bases, they aid the navigator throughout the world.

Radio range beacons transmit dot-dash (A) and dash-dot (N) signals in alternate quadrants. Neighboring quadrants overlap, forming a narrow beam identified by a continuous signal which is a result of the overlapping of the A and N signals. These narrow, wedge-shaped beams, or equisignal zones, indicate to the pilot that he is flying the safest on-course heading to approach or depart from the desired radio range station. The quadrant signals of

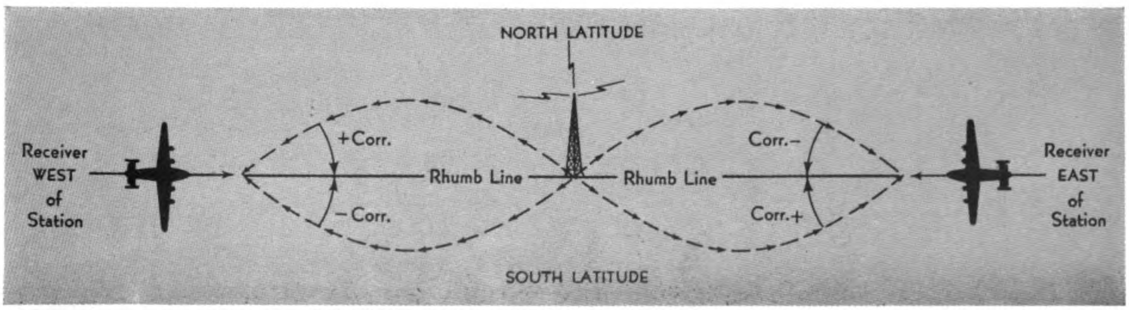


FIG. 66—DETERMINING SIGN OF MERCATOR CORRECTION



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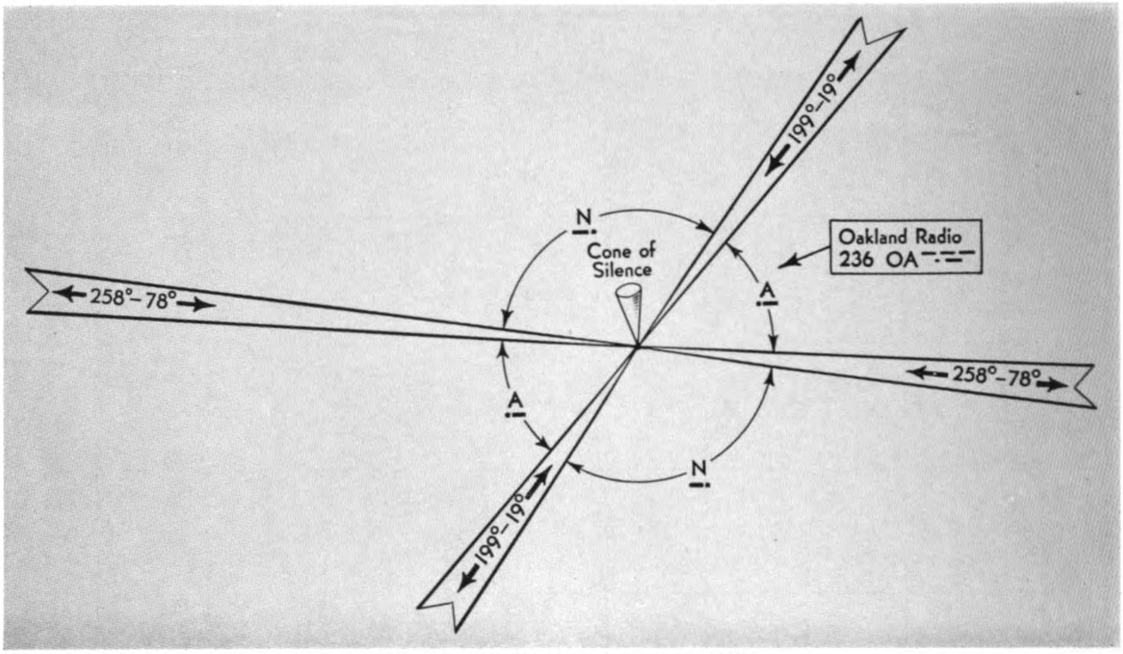


FIG. 67—TYPICAL RADIO RANGE

dot-dash and dash-dot (A and N) indicate to him the side of the equisignal zone from which he is approaching the station, or toward which he is drifting. When the radio compass is used for range reception, the master switch is on REC COMP. However, when the switch is on REC COMP, range reception is not entirely reliable. Therefore, the on-course range signal should be checked frequently by turning the switch to REC ANT, which is the best position for radio range reception.

**Procedure**—To follow a radio range course, it is necessary to have a chart (as illustrated in Figure 67) showing the radio range course and characteristics. The magnetic direction of the courses to and from the station are indicated, as are the locations of the A and N quadrants with relation to the various equisignal zones. The frequency and identification signals of the station also are noted. The procedure is as follows:

a. Adjust the master switch to REC ANT.

**Note:** In case of rain-static, adjust master switch to REC LOOP and rotate loop parallel to radio wave for maximum signal strength.

b. Turn aircraft so as to intercept the radio range course. When *on-course*, the A and N signals will blend into a continuous dash, only interrupted by station identification.

c. As the aircraft approaches the station the volume increases, but on arrival over the station, a decrease in volume occurs as the plane passes over what is known as the "cone of silence." If the master switch is on REC LOOP, the cone of silence will not be "heard."

## USE OF RADIO BEARINGS

**Properties and Limitations**—True radio bearings are very useful aids to the aerial navigator who thoroughly understands their properties and limitations. These may be summarized as follows:

1. A true radio bearing is the direction of the transmitting station from the receiver relative to true North. If the receiver is an aircraft, the reciprocal of the bearing would be plotted through the known geographical position of the transmitting station.

2. The bearing is a position line; that is, it establishes the aircraft's position as somewhere on the straight line passing through the transmitting station. It does not, however, indicate the aircraft's distance from the station.



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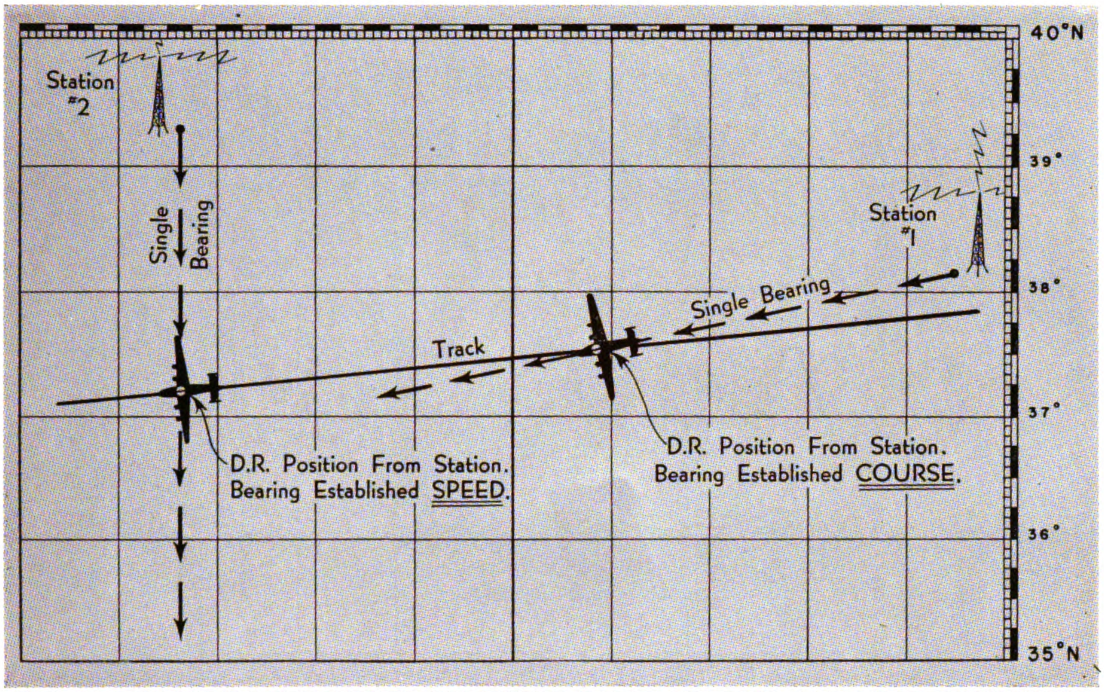


FIG. 68—POSITION DETERMINED BY SINGLE RADIO BEARING AND DEAD RECKONING

3. The bearing is a great circle, and if it is to be plotted on a Mercator chart, it must first be converted to a rhumb line bearing.

4. The bearing may not be absolutely accurate; therefore, the navigator should analyze it carefully to determine the most likely position of the aircraft, allowing for any estimated errors.

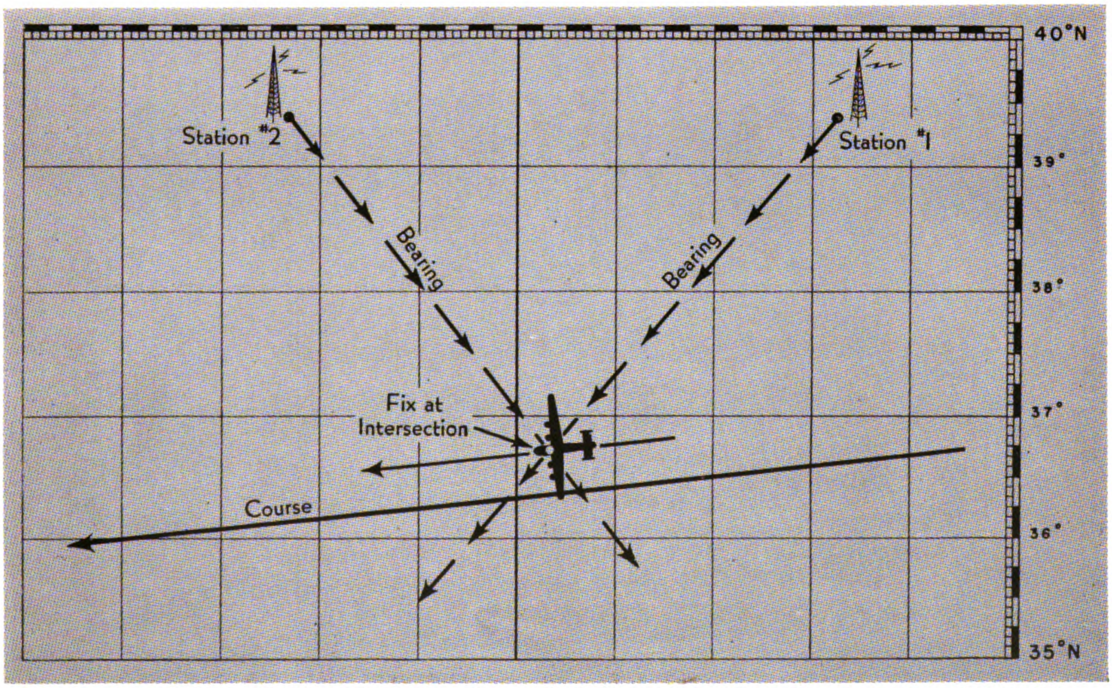


FIG. 69—POSITION DETERMINED BY INTERSECTION OF TWO RADIO BEARINGS



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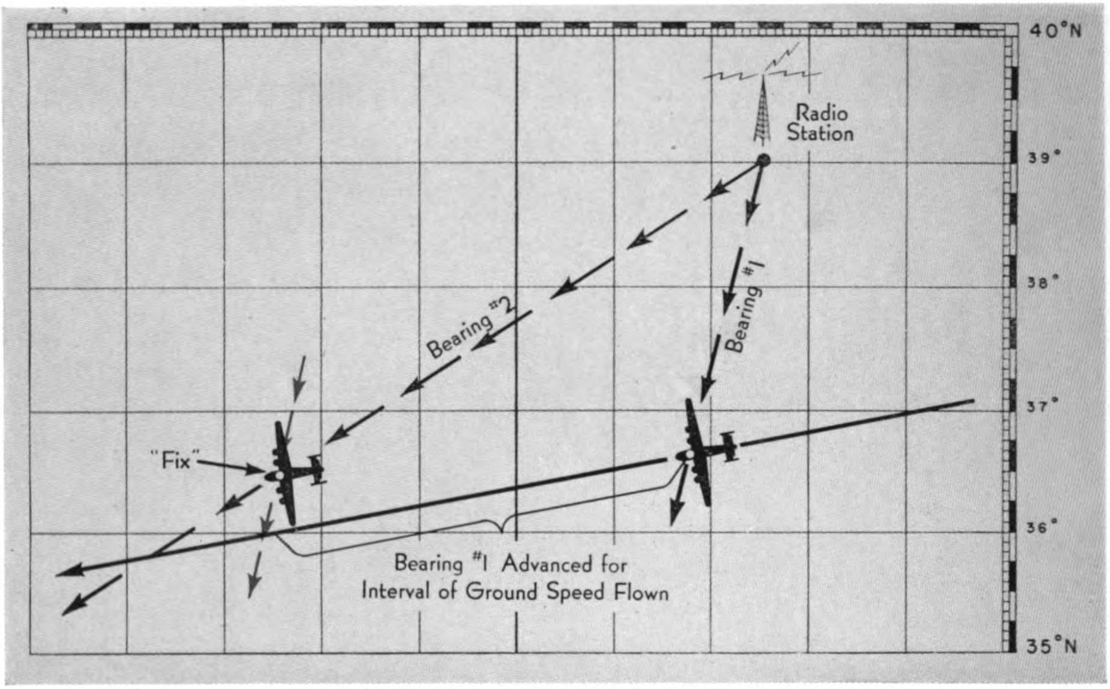


FIG. 70—POSITION DETERMINED BY TWO BEARINGS ON SAME STATION

**Obtaining Fix—**Methods most often used to determine the aircraft's position by use of radio bearing lines are as follows:

1. **Single Bearing and Dead Reckoning** (Figure 68)—With only a single radio bearing the navigator may, by reasoning and deduction, estimate the aircraft's most probable dead reckoning position on the radio position line.

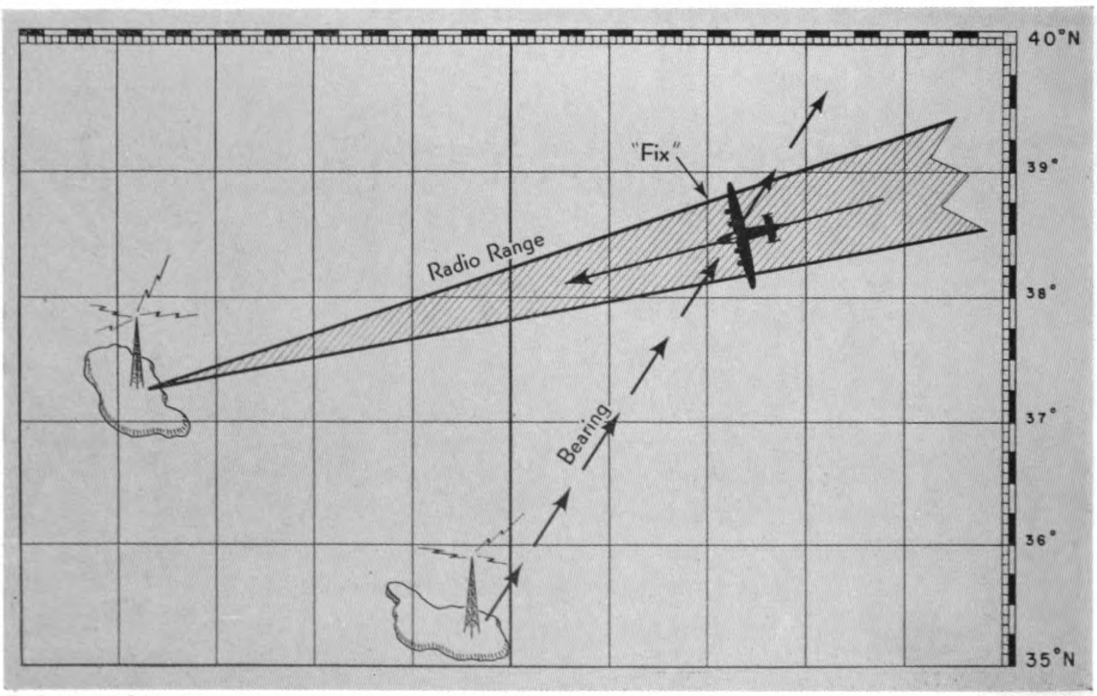


FIG. 71—POSITION DETERMINED BY RADIO BEARING AND ON-COURSE RANGE SIGNAL



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If the bearing is parallel to the track, it will serve to check the aircraft's track. If the bearing is at right angles to the track it will serve to check the aircraft's speed.

2. **Two or More Bearings of Different Stations** (Figure 69)—A single radio bearing establishes the aircraft's position as being somewhere on the bearing line. But when two or more bearings are taken of different stations at the same time, the only position possible to the aircraft is at the intersection of these bearing lines, hence its exact location is determined (assuming no errors).

3. **Running Fix** (two bearings of same station) (Figure 70)—With the track (or course) and ground speed of the aircraft known, a position fix can be determined by taking two bearings of the same station, allowing an interval of time between bearings. During this time interval the bearing of the station will alter due to the change of position of the aircraft. And because the aircraft was located somewhere on each bearing line (at the instant the bearing was taken), the first bearing line can be advanced along the track a distance equal to the product of ground speed and time interval between bearings. The intersection of bearings establishes the aircraft's position.

4. **Bearings Intersecting Range Courses** (Figure 71) — Bearings intersecting range courses establish position of the aircraft in the same way as do two or more bearings taken of different stations. The radio range establishes the course of the aircraft, and a bearing taken on another station will intersect the range course, establishing the aircraft's position from the range station.

## PROBLEM WORK

No. 12 Draw relative radio bearing diagram.

No. 13 Draw diagram showing how sign of Mercator correction is determined.



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**PROBLEM WORK NO. 14**

**RADIO BEARINGS**

(Convert relative radio bearing to true Mercator bearing.)

| No. | Relative Bearing | Calibration Correction | Corrected Relative Bearing | Compass Heading | Var. | Dev. | True Heading | True Great Circle Bearing | Mercator Correction | Mercator Bearing From Station |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 330° | —10° | | 270° | 5°E | 0° | | | —1° | |
| 2 | 200° | +10° | | 310° | 7°E | 2°E | | | —1° | |
| 3 | 25° | +10° | | 45° | 15°W | 1°W | | | —4° | |
| 4 | 45° | +15° | | 185° | 18°W | 4°E | | | +1° | |
| 5 | 100° | — 5° | | 140° | 10°E | 1°E | | | +3° | |
| 6 | 360° | 0° | | 77° | 7°W | 7°W | | | +4° | |
| 7 | 180° | 0° | | 295° | 14°E | 4°W | | | 0° | |
| 8 | 10° | + 5° | | 315° | 0° | 3°E | | | +2° | |
| 9 | 90° | 0° | | 70° | 5°E | 2°W | | | 0° | |
| 10 | 270° | 0° | | 360° | 11°W | 10°E | | | —2° | |
| 11 | 350° | — 5° | | 100° | 17°E | 4°E | | | +4° | |
| 12 | 20° | + 7° | | 340° | 13°W | 6°W | | | —3° | |
| 13 | 70° | + 5° | | 50° | 4°E | 2°E | | | 0° | |
| 14 | 30° | +10° | | 210° | 9°E | 3°W | | | +2° | |
| 15 | 320° | —15° | | 17° | 11°W | 2°W | | | —3° | |
| 16 | 15° | + 6° | | 289° | 16°E | 5°E | | | —1° | |
| 17 | 105° | —11° | | 73° | 10°E | 6°E | | | —4° | |
| 18 | 210° | +12° | | 359° | 4°W | 4°W | | | —3° | |
| 19 | 50° | + 7° | | 178° | 11°E | 2°W | | | —1° | |
| 20 | 170° | — 6° | | 46° | 1°E | 1°W | | | +1° | |



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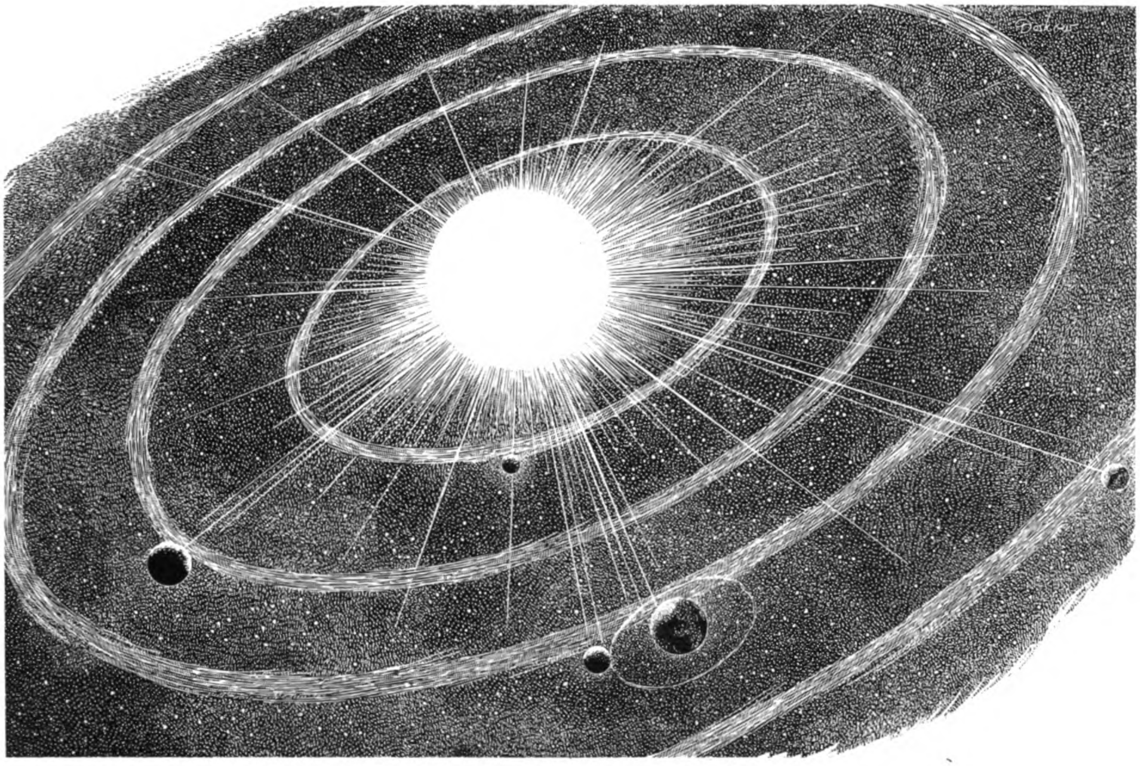

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# CELESTIAL SPHERE

WHEN surface features of the earth are visible, the position of an aircraft can be determined very accurately by pilotage (navigation with reference to prominent landmarks). Two other methods of determining the position of an aircraft—radio navigation and dead reckoning navigation—have been described in preceding chapters.

Each of these methods of navigation, however, is subject to certain limitations. In dead reckoning, for example, the direction and velocity of the wind seldom are accurately known, and as a consequence an element of error always is present in the determination of a DR position. This error is *cumulative,* that is, it becomes progressively larger the farther the DR position is from a known position or fix. In long-range ocean flying it usually is impossible to check DR positions by reference to landmarks, such landmarks seldom being available. This fact makes navigation by DR unreliable, and navigation by pilotage impossible. Finally, mechanical factors and atmospheric conditions can cause radio bearings to be in error.

Thus it is apparent that any one, or all three of these methods of navigation might prove unreliable at any given time. Therefore, it is essential that the navigator preparing for long-range ocean flying learn still another method of determining his position—celestial



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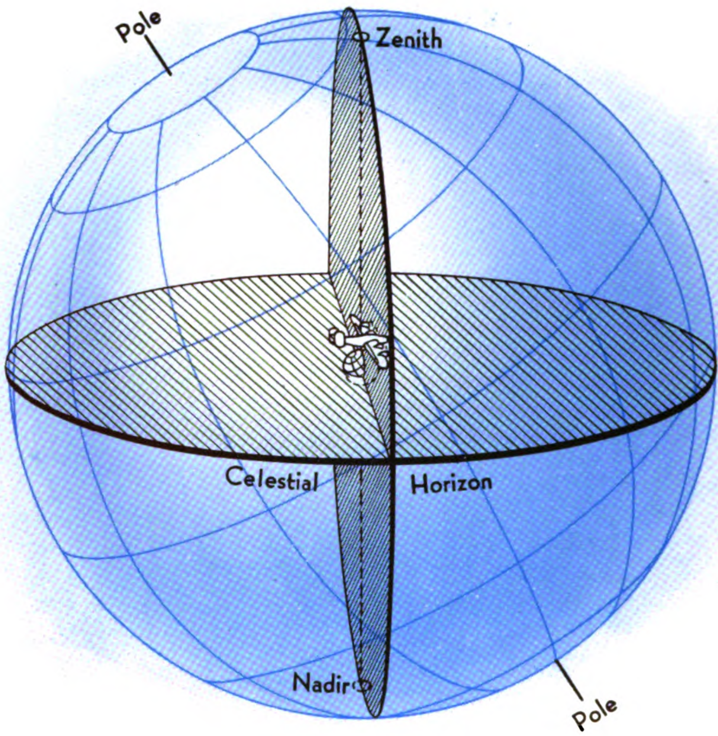


FIG. 72—ZENITH, NADIR, CELESTIAL HORIZON

navigation. Equipped with a knowledge of all four of these basic methods of navigation, he then can feel confident in flight over water or land, under any conditions.

The transition from navigation with reference to the earth to navigation with reference to celestial bodies is, in a sense, like stepping from solid earth into space. In "celestial," as the term is abbreviated, the navigator must acquire new mental habits. His vocabulary becomes enlarged with the addition of many new words and phrases. Even more important, his concept of the world and the universe undergoes a striking change. In learning celestial, the navigator must begin to reason in terms of infinity because, as pointed out earlier, the entire universe becomes his workshop. He learns to call the stars and planets by name, and to regard them as his assistants.

Though it appears complex at first glance, celestial navigation is, in reality, simplicity itself. As in DR, a thorough working knowledge of the language of celestial is essential to a firm foundation in this method of navigation. The following terms, therefore, should be studied carefully and conscientiously, and it is strongly recommended they be memorized. It is not suggested that the navigator necessarily memorize the definitions as stated herewith, but that—more importantly—their *meaning* be committed to memory.

## TERMS

**Celestial Sphere**—The celestial sphere is a vast globe of infinite radius, the center of which is considered to be located at the center of the earth, and upon which the celestial bodies are projected.

Actually, such a globe does not exist, but to an observer on the earth's surface looking up toward heavenly bodies whose distances from him are infinitely great, the universe ap-



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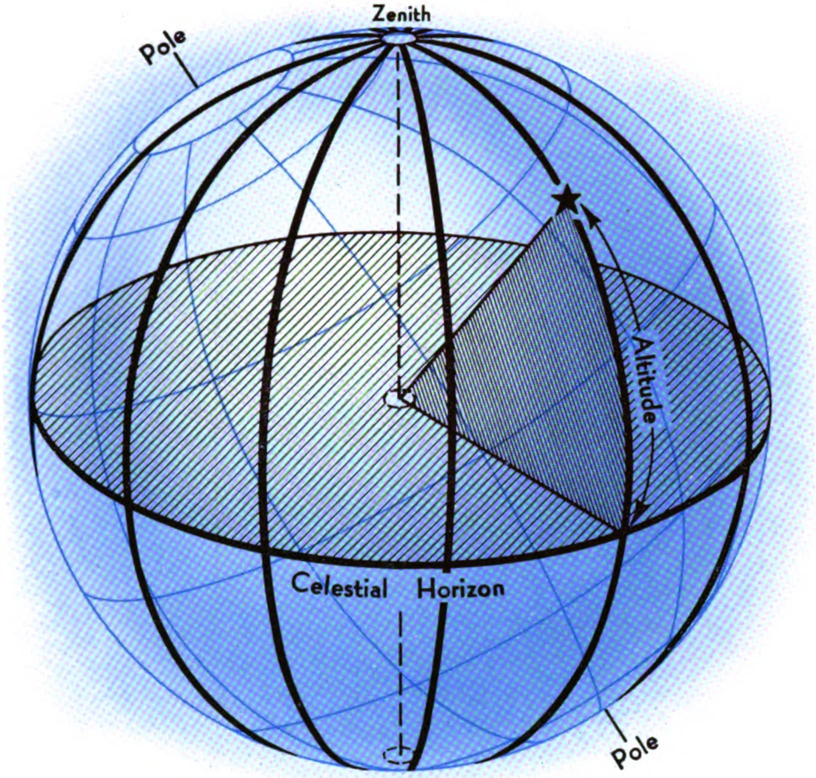


FIG. 73—VERTICAL CIRCLES, ALTITUDE

pears to be contained in a vast hollow sphere. The *distances* of these bodies from the earth do not interest the navigator, since their relative directions, not their distances, determine the observer's position.

**Zenith**—The zenith is that point on the celestial sphere directly above the observer (Figure 72). It is apparent, therefore, that as the observer changes position, his zenith moves with him. This is a most important concept, as upon it largely depends the navigator's ability to locate himself by reference to the celestial sphere.

**Nadir**—The nadir is that point on the celestial sphere directly beneath the observer (Figure 72). Since, like the zenith, this point is established by the observer's position, it too will move with him as he changes his position.

**Celestial Horizon**—The celestial horizon is a great circle on the celestial sphere whose plane passes through the center of the earth at right angles to a line joining the zenith and nadir (Figure 72). It serves as a reference circle *from which* the *altitude* of a celestial body is measured, and *along which* the body's East-West position may be determined with reference to an observer.

**Vertical Circle**—Vertical circles are great circles on the celestial sphere passing through the zenith and nadir. These serve as reference circles *along which* the *altitude* of celestial bodies is measured, and hence are sometimes called circles of altitude (Figure 73).

**The Prime Vertical** is the vertical circle that passes through the East and West points of the celestial horizon (Figure 74).

**Altitude**—The altitude of a celestial body is the angular distance from the celestial horizon to the body, as measured upon the vertical circle passing through the body. (Figures 73, 74). It is one of two coordinates (known as the *horizon coordinates*) by means of which the po-



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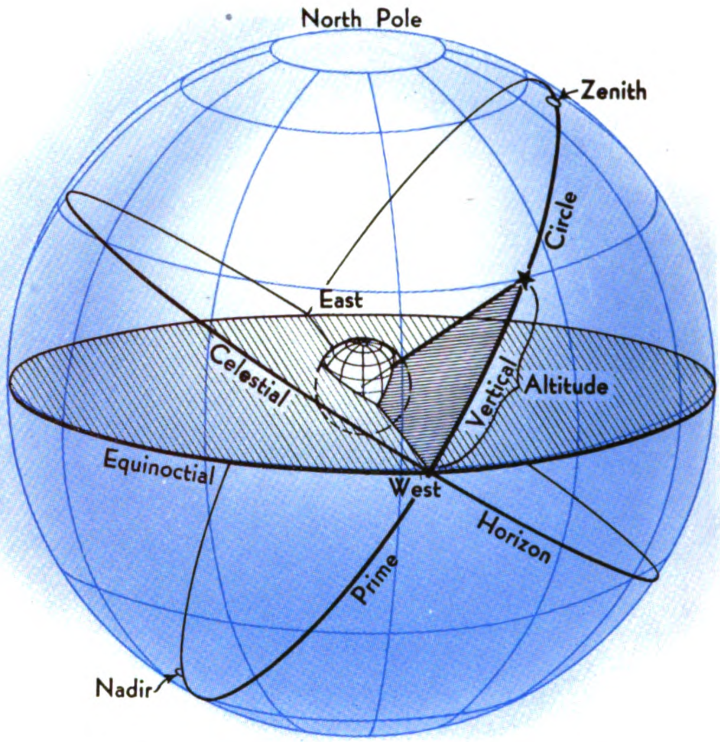


FIG. 74—EQUINOCTIAL, PRIME VERTICAL

sition of a celestial body may be located with reference to the observer's position.

**Equinoctial, or Celestial Equator** — The equinoctial, or celestial equator, is the great circle on the celestial sphere formed by extending the plane of the earth's equator to the sphere (Figure 74). It serves as a reference circle *from which* the North-South position of a celestial body is measured.

The equinoctial intersects the horizon at its East and West points.

**Hour Circles**—Hour circles are great circles on the celestial sphere passing through the North and South celestial poles. They serve as reference circles *along which* the *declination* of celestial bodies is measured, hence are sometimes called circles of declination (Figure 75).

**Declination** (dec.)—Declination of a celestial body is its angular distance from the equinoctial measured on the hour circle passing through the body (Figure 75). It is named North or South according to its direction from the equinoctial. It is one of two coordinates (known as the *equinoctial coordinates*) by means of which the position of a celestial body may be located in space with reference to fixed points. Declination corresponds to latitude on the earth.

**Celestial Coordinates**—Coordinates of any kind are simply a means of locating an object with respect to two reference lines at right angles to each other. A familiar example of this is the locating of a house in a city. If a house is at the corner of 7th Street and 3rd Avenue, then its coordinates are 7 and 3. That is, it is 7 blocks North or South of the street used for North-South reference, and 3 blocks East or West of the avenue used for East-West reference. The house might also be located geographically by stating its latitude (North or South) and longitude (East or West). In



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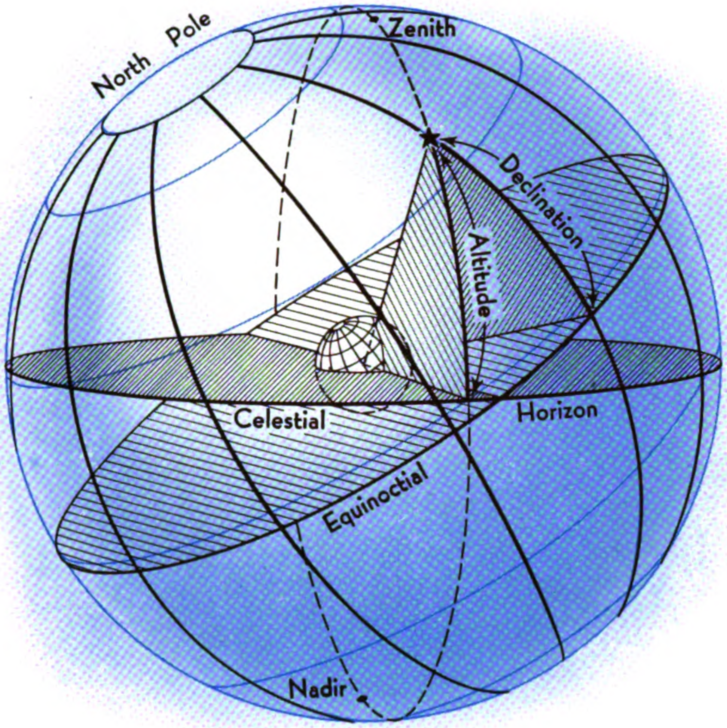


FIG. 75—HOUR CIRCLES, DECLINATION

the latter case, a different set of coordinates and reference lines would be employed than those used to establish position of the house in the city. There is a close parallel between the reference means used in the foregoing example, and those used to locate a celestial body in the sky.

For purposes of celestial navigation, two sets of coordinates, together with their reference circles, are used. The name of the primary reference circle used, in each case, gives rise to the name of the coordinate system. Thus, there is the horizon system of coordinates, and the equinoctial system.

The horizon system is established, basically, with relation to the observer's zenith. And since, as already explained (see definition of zenith), the zenith moves with the observer, the horizon coordinates of a celestial body (altitude and azimuth) change as his position changes.

The equinoctial system, on the other hand, since it is derived from fixed points on the earth which are merely projected to the celestial sphere, constitutes a *fixed* system of coordinates. Hence the equinoctial coordinates (declination and hour angle), do *not* change with a change in the observer's position, but have definite values for any given instant of time. This makes possible the calculation of these values in advance, hence they can be tabulated for the navigator's use. (See Air Almanac, Chapter VI.) Using these tabulated values, the navigator can *compute* the horizon coordinates, which in turn make it possible for him to fix his position.



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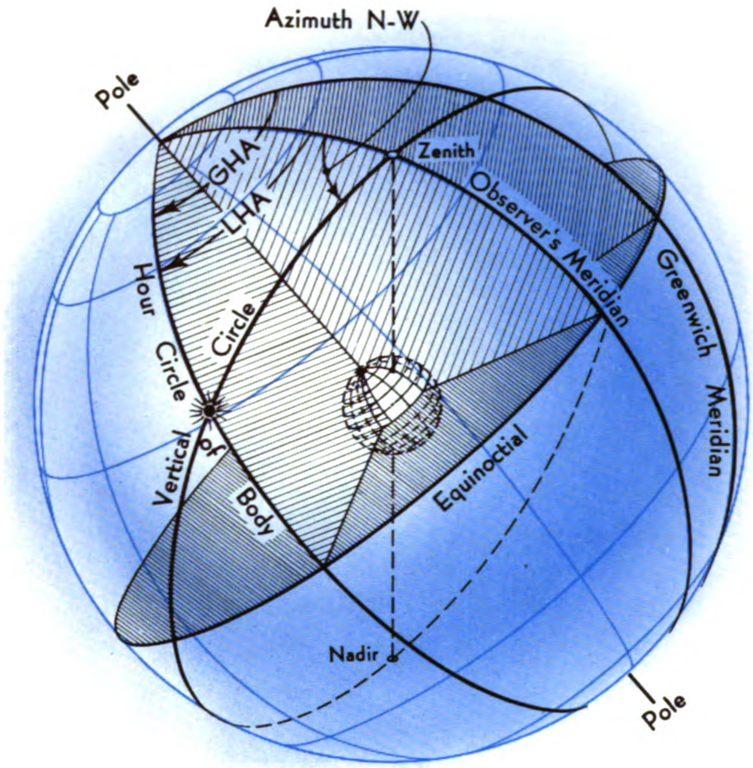


FIG. 76—AZIMUTH, LOCAL AND GREENWICH HOUR ANGLE

**Azimuth** (Az)—Azimuth is the bearing of a celestial body at the observer (Figure 76). It is the angle at the zenith between the celestial meridian of the observer and the vertical circle passing through the celestial body. It is measured from the elevated pole (North in North latitude, South in South latitude) and to the East or West through 180° (East when the celestial body is rising, and West when it is setting). Azimuth is the second of the two horizon coordinates by means of which a celestial body is located with reference to an observer.

**Local Hour Angle** (LHA)—The local hour angle of a celestial body is an arc of the equinoctial measured from the upper branch of the observer's meridian over West through 360° to the hour circle passing through the body (Figure 76). It also may be defined as the angle at the pole between the meridian of the observer and the hour circle passing through the body. It is the second of the two equinoctial coordinates used to locate a body with relation to fixed points.

**Greenwich Hour Angle** (GHA) — The Greenwich hour angle of a celestial body is an arc of the equinoctial measured from the Greenwich meridian over West through 360° to the hour circle passing through the body (Figure 76). It also may be defined as the angle at the pole between the Greenwich meridian and the hour circle passing through the body. GHA corresponds to longitude on the earth.

**Ecliptic**—The ecliptic is the great circle path on the celestial sphere that the sun appears to follow due to the annual revolution of the earth (Figure 77). It is inclined to the equinoctial at an angle of approximately



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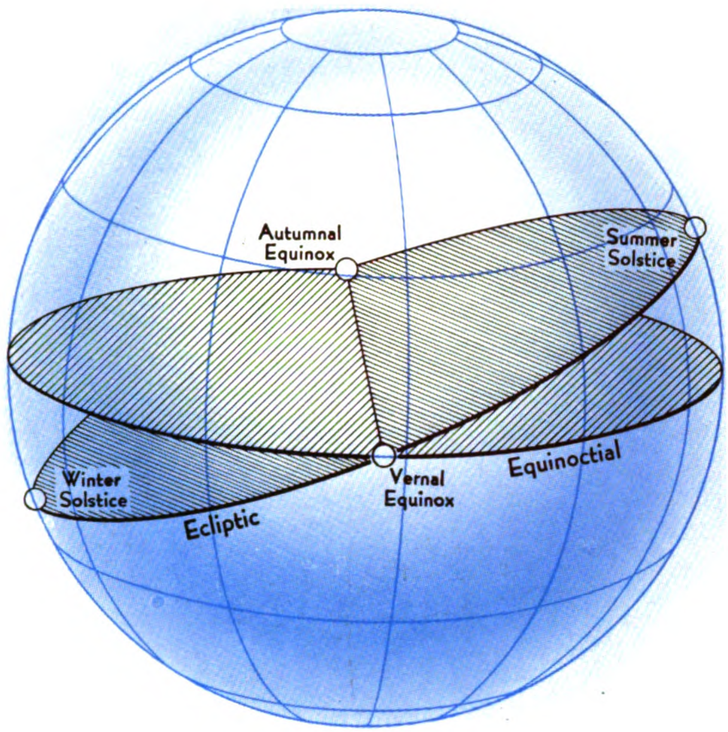


**FIG. 77—ECLIPTIC, EQUINOXES, SOLSTICES**

23°27′30″. This inclination is called the obliquity of the ecliptic.

**Equinoxes**—The equinoxes are the points in the celestial sphere where the ecliptic intersects the equinoctial (Figure 77).

1. **Vernal Equinox** [called First Point of Aries (♈)] is that point on the equinoctial which the sun passes in changing from South declination to North declination. It occurs about March 21st and marks the beginning of spring in the Northern hemisphere.

2. **Autumnal Equinox** (called First Point of Libra) is that point on the equinoctial which the sun passes in changing from North declination to South declination. It occurs about September 21st and marks the beginning of autumn in the Northern hemisphere.

**Solstices**—The solstices are the points on the ecliptic where the sun attains maximum declination, Northerly or Southerly (Figure 77). The point of maximum Northerly declination is termed Summer Solstice (about June 21st). The point of maximum Southerly declination is termed Winter Solstice (about December 21st). The occurrence of the summer solstice results in the longest period of daylight in one day throughout the year, and conversely the winter solstice brings the shortest period of daylight in one day.

Thus the position of the earth along the ecliptic (or *apparent* position of the sun) determines the seasons of the year. The reason for this is evident when it is realized that the seasons depend primarily on the amount of heat which the earth receives from the sun, and in turn, the amount of heat received depends upon the position of the earth relative to the sun. The earth's axis, it will be remembered, is inclined at an angle to the ecliptic, hence when the North pole is tilted *towards* the sun, the Northern hemisphere receives a maximum



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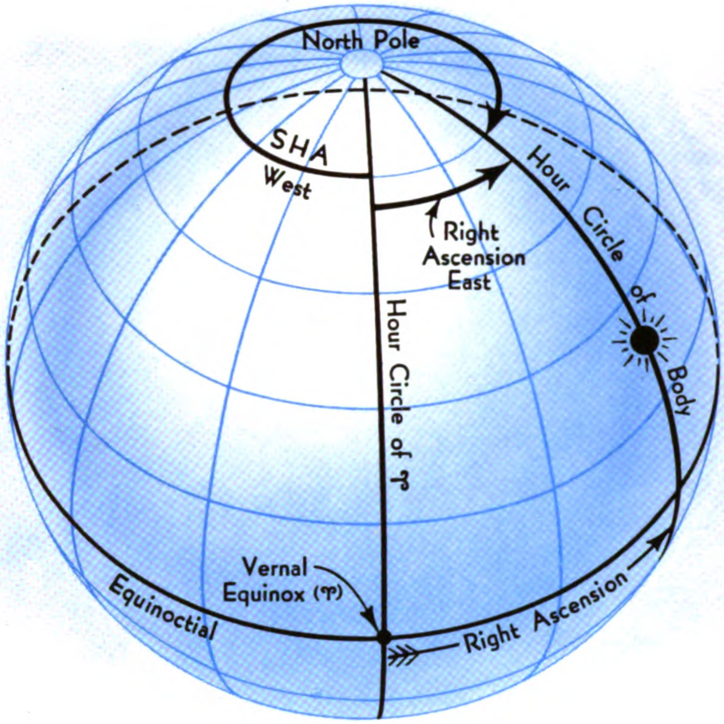


FIG. 78—RIGHT ASCENSION, SIDEREAL HOUR ANGLE

amount of heat per unit area and so experiences summer. When the North pole is inclined *away* from the sun, the Northern hemisphere receives a minimum amount of heat per unit area and so experiences winter.

**Right Ascension** (RA)—Right ascension is the angle at the pole between the hour circle of the First Point of Aries and the hour circle passing through the body, measured to the *East* through 24 hours or 360° (Figure 78). It also may be described as the arc of the equinoctial intercepted between these hour circles. Right ascension seldom is used in aerial navigation due to the convenience of modern air almanacs, which are tabulated in sidereal hour angle.

**Sidereal Hour Angle** (SHA) — Sidereal hour angle is related to right ascension in that SHA equals 360° minus RA (Figure 78). Stated as an equation:

$$\mathrm{SHA} + \mathrm{RA} = 360°$$

It is the angle at the pole (measured to the *West* through 360°) between the hour circle of the First Point of Aries and the hour circle passing through the body. Sidereal hour angle is used to find GHA of all star sights in aerial navigation.

**Astronomical Triangle**—The intersections of the observer's (celestial) meridian, the hour circle passing through a celestial body, and the vertical circle passing through a celestial body form a spherical triangle on the celestial sphere known as the *astronomical triangle* (Figure 79). The sides and angles of this triangle represent the relationship existing between the observer's position, and the horizon coordinates and equinoctial coordinates of a celestial body. If the approximate latitude of the observer is known, together with the hour angle and declination of the celestial body, then the altitude and azimuth of the body can be computed. The values thus obtained can then be used to determine the observer's position by methods to be discussed in later chapters.

The solution of the astronomical triangle, then, is the navigator's fundamental problem



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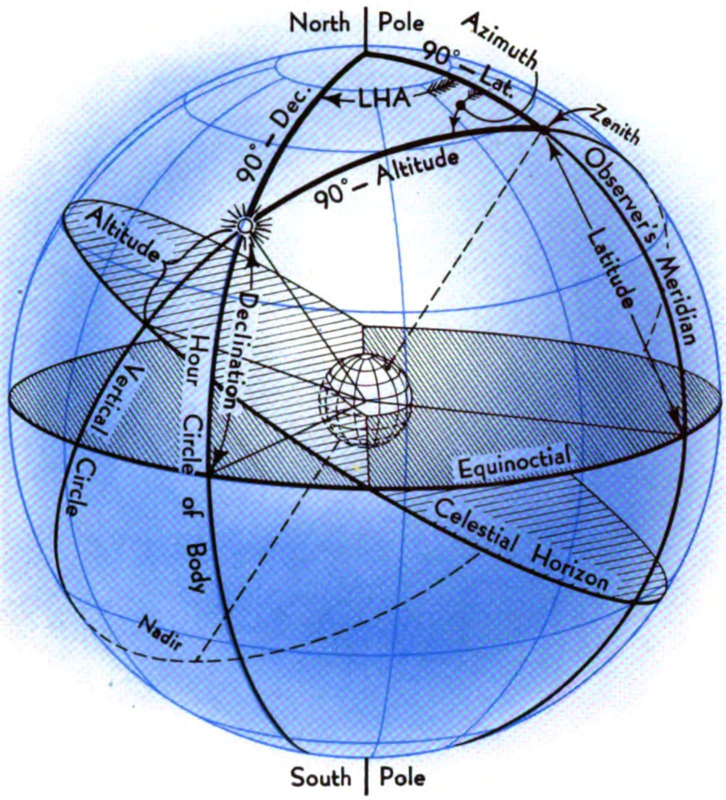


FIG. 79—ASTRONOMICAL TRIANGLE

in celestial navigation. This solution is based on formulas of spherical trigonometry. It is not necessary for the aerial navigator to know these formulas, however, except for his own interest, as the various possible solutions of the astronomical triangle have been worked out for him and compiled into tables of precomputed altitude and azimuth. From these, the desired information may be obtained by inspection.

The aerial navigator should learn how to draw the astronomical triangle, and should know its component parts, as this knowledge will help him to become familiar with the terminology of celestial navigation. In this triangle, the local hour angle (which is the angle at the pole) is the most important angle, as it determines the observer's longitude.

In drawing this triangle, remember that it is formed by three great circles:

1. Hour circle passing through the body.
2. Celestial meridian passing through the zenith.
3. Vertical circle passing through the body.



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## PROBLEM WORK NO. 15

## CELESTIAL SPHERE

(Show the following information.)

1. Observer's meridian
2. Greenwich meridian
3. Hour circle
4. Celestial poles
5. Zenith
6. Equinoctial
7. Ecliptic
8. Vernal equinox
9. Longitude of observer
10. Latitude
11. GHA
12. LHA
13. Declination
14. SHA
15. Solstices
16. Right ascension



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## PROBLEM WORK NO. 16

## ASTRONOMICAL TRIANGLE

(Show the following information.)

1. Celestial poles
2. Zenith and nadir
3. Equinoctial
4. Celestial horizon
5. Astronomical triangle
6. Latitude
7. Zenith distance
8. LHA
9. Azimuth
10. Altitude
11. Declination
12. Polar distance



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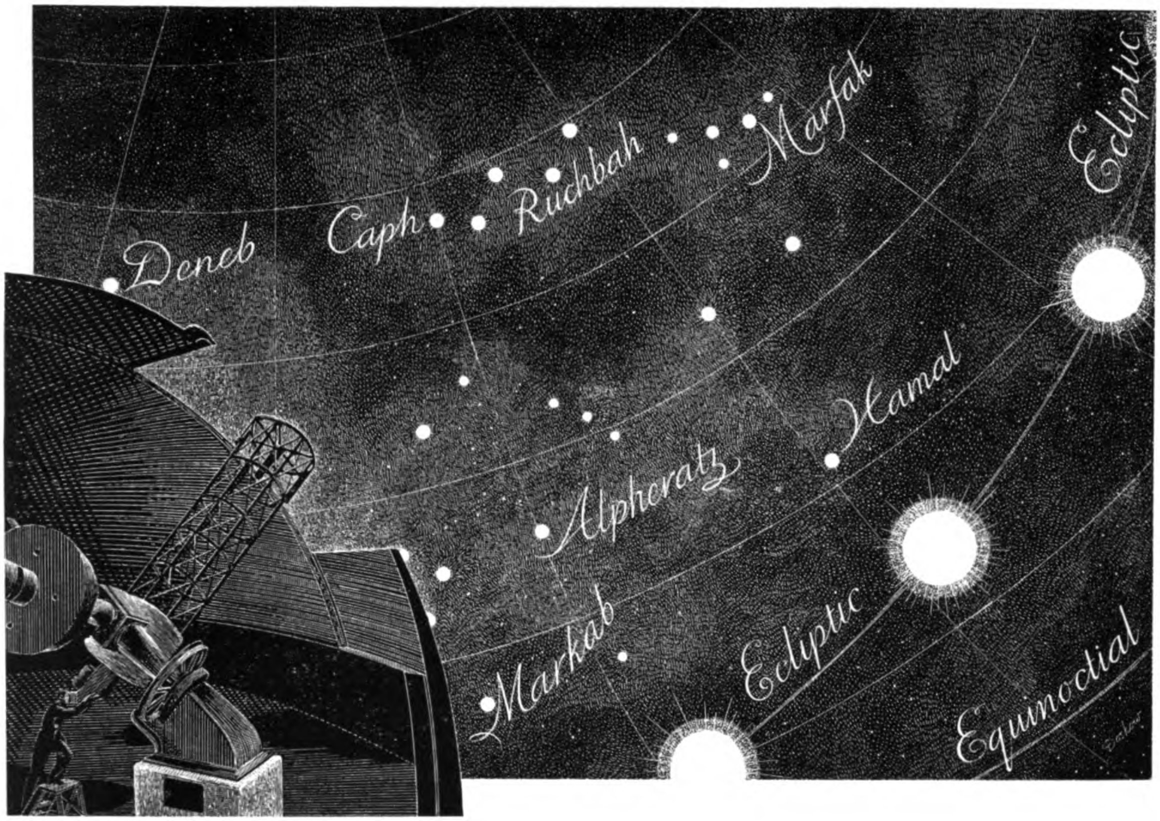


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# AIR ALMANAC

THE American Air Almanac is one of the aerial navigator's principal tools and, therefore, is deserving of careful study. The navigator should understand this indispensable volume thoroughly, because it provides him with the astronomical data required for aerial navigation. (See Appendix for sample Air Almanac pages.)

As compared with the Nautical Almanac, the information in the Air Almanac contains a certain amount of error. However, the average error is only about 0'.5, which is so slight as to be considered negligible. This error has been allowed in order to permit presentation of the information in a more condensed and convenient form, thus making possible faster solution of celestial navigation problems, the most important being the solution of the astronomical triangle.

As explained in the previous chapter, in order to solve the astronomical triangle, the navigator must know the equinoctial coordinates (GHA and declination) of a body (Figure 80). These have been precomputed and tabulated for him in the Air Almanac. Government astronomers are assigned to the important work of predetermining, for any given instant of GCT, the exact location of all heavenly bodies useful to navigators. The findings of these astronomers are published in advance in the Air Almanac, which is printed three times annually. All in-



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formation needed for any given day's navigation is printed on front and back sides of a single page of the Almanac.

**Note:** *To avoid the possibility of using day-old data by mistake, it is advisable to tear out each daily page as soon as it becomes obsolete.*

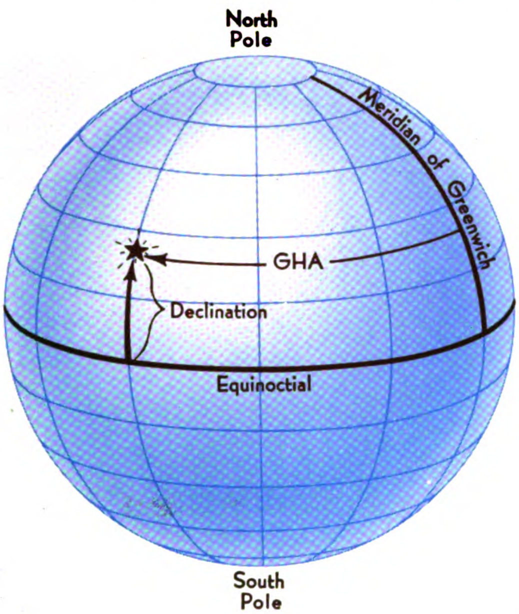


FIG. 80—EQUINOCTIAL COORDINATES

## GHA AND DEC

**Greenwich Hour Angle (GHA) and Declination (Dec.) of Sun, Moon, and Planets**—On the daily page of the Air Almanac are listed the GHA of the sun, moon, and planets (most suitable for observation). Declination of the sun and planets is given in hourly intervals, while declination of the moon is tabulated in ten-minute intervals of GCT throughout 24 hours.

In taking this data from the Almanac, the correct declination will be the nearest tabulated value for any given instant of GCT. To obtain the correct GHA, however, it is necessary, first, to find the value listed for the preceding ten-minute interval of GCT, and then to add to it an interpolated amount of GHA for the additional minutes and seconds. These interpolation values may in turn be obtained directly from tables printed on the inside of the front cover and also on the back of the star chart.

The moon has an interpolation table separate from the other celestial bodies due to its proximity to the earth and its relatively rapid movement.

**GHA and Declination of a Star** (Figure 81)—In navigation the stars are considered to be fixed bodies in space. Therefore, their relative positions are always the same. This fact is used to advantage in the Air Almanac. Instead of giving the GHA of each individual star, the Almanac lists the daily positions of the *First Point of Aries* or *vernal equinox,* as measured by its Greenwich hour angle. On the inside of the back cover, the sidereal hour angles (SHA) of the 55 brightest stars are listed, and the SHA of an additional nine stars are listed on the opposite page. SHA, as explained earlier, is the position of a star with reference to the First Point of Aries, measured to the West from the First Point of Aries.

Hence:

GHA (star) = GHA (Aries) + SHA (star)

The change in declination of a star for the four-months period which the Air Almanac covers is practically negligible. Therefore, declination is listed opposite the SHA on the in-

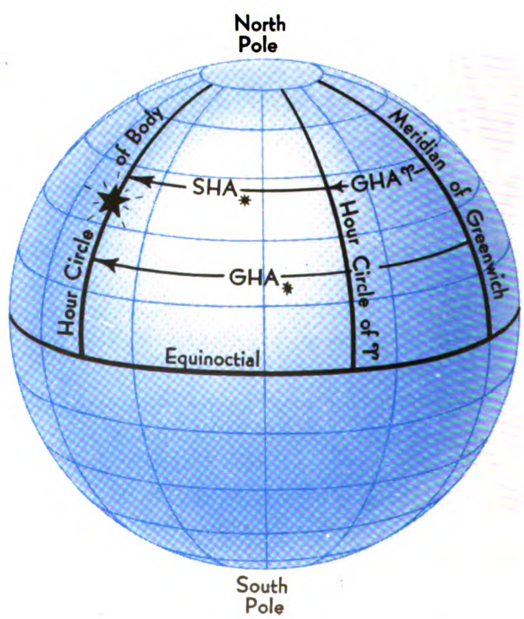


FIG. 81—GHA* = GHA ♈ + SHA*



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side back cover, and it may be read directly for any given star.

*Examples*:

Jan. 1, 1943, GCT $10^h12^m22^s$. Find GHA and declination.

| | | Sun |
|---|---|---|
| GCT $10^h10^m$ | GHA | 331°41′ |
| + for $02^m22^s$ | Corr. | 36′ |
| GHA for $10^h12^m22^s$ | | 332°17′ |
| Declination | | S 23°03′ |

| | | Saturn |
|---|---|---|
| GCT $10^h10^m$ | GHA | 187°27′ |
| + for $02^m22^s$ | Corr. | 36′ |
| GHA for $10^h12^m22^s$ | | 188°03′ |
| Declination | | N 19°36′ |

| | | Moon |
|---|---|---|
| GCT $10^h10^m$ | GHA | 42°52′ |
| + for $02^m22^s$ | Corr. | 34′ |
| GHA for $10^h12^m22^s$ | | 43°26′ |
| Declination | | S 7°13′ |

| | | Star |
|---|---|---|
| GCT $10^h10^m$ | GHA ♈ | 252°41′ |
| + for $03^m22^s$ | Corr. | 36′ |
| SHA* (Sirius) | | 259°21′ |
| | GHA* | 412°38′ |
| | | —360° |
| GHA for $10^h12^m22^s$ | | 152°38′ |
| Declination | | S 16°38′ |

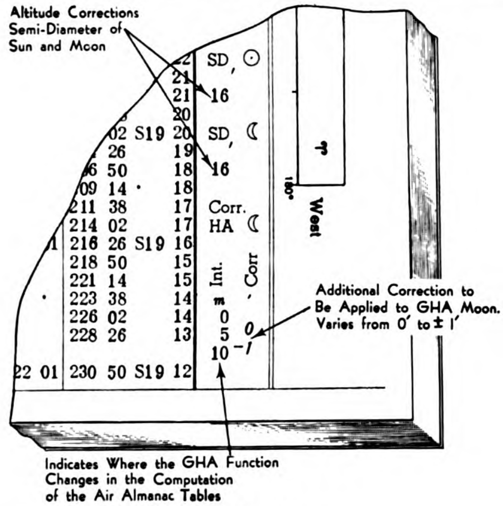


FIG. 82

**Note:** In lower right corner of the A. M. side of the daily page is the notation shown in Figure 82.

## HOUR ANGLE DIAGRAMS

**Description**—The *hour angle diagram* is a graphic method of illustrating the relationship between the meridian of Greenwich, meridian of the observer, and the hour circle of a body. It is important because it aids the navigator in visualizing GHA, LHA, and longitude.

This relationship may be illustrated on a globe (Figure 83).

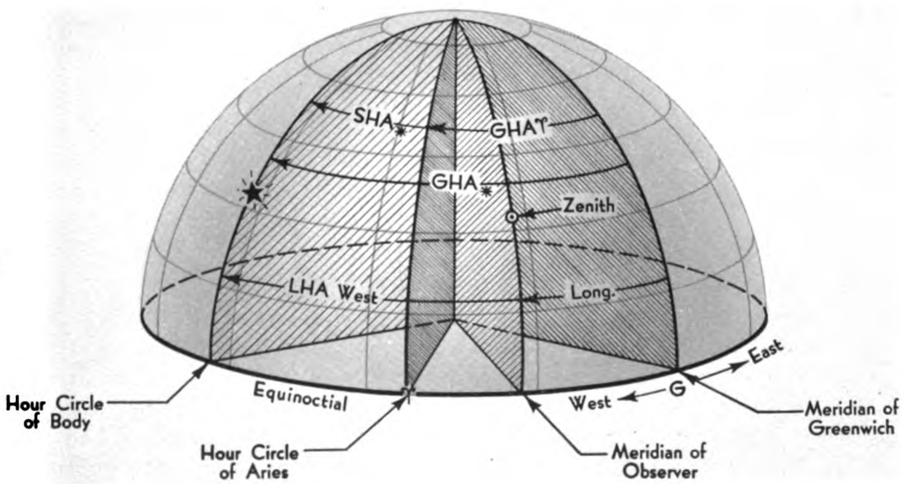


FIG. 83—RELATIONSHIP BETWEEN OBSERVER'S MERIDIAN, GREENWICH MERIDIAN AND HOUR CIRCLE OF BODY



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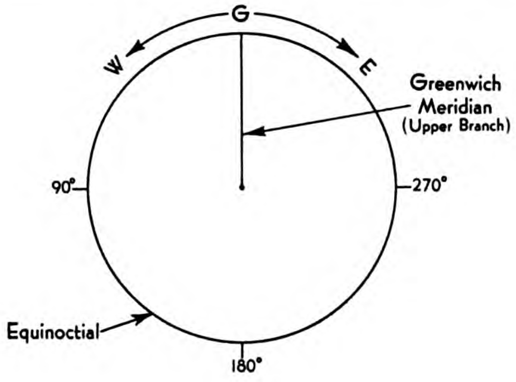


FIG. 84—BASIC HOUR ANGLE DIAGRAM

The easiest method of drawing hour angle diagrams, however, is on the plane of the equinoctial, in which case the globe is considered to be viewed from the South pole. The equinoctial thus appears as a circle, and the meridians or hour circles appear as straight lines radiating from the center. The meridian of Greenwich is drawn from the top of the circle to the center, and directions measured to the left are named West, and those measured to the right are named East (Figure 84). This diagram can be used to indicate any relationship of hour angle and longitude.

*Examples*:

**As Used for Sun** (Figure 85)

| | | |
|---|---|---|
| Given: | Long. | 160° East |
| | GHA | 125° West |
| Indicate: | LHA of Sun | |

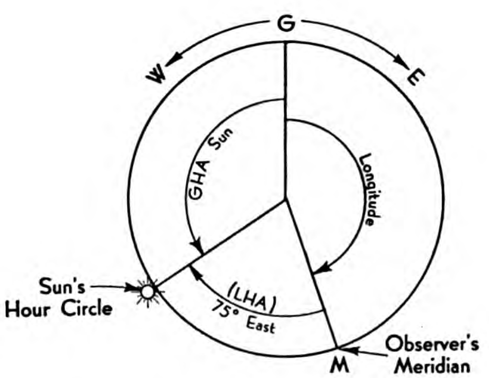


FIG. 85—HOUR ANGLE DIAGRAM FOR SUN

**As Used for Star** (Figure 86)

| | | |
|---|---|---|
| Given: | Long. | 170° West |
| | GHA ♈ | 120° West |
| | SHA* | 150° West |
| Indicate: | LHA of Star | |

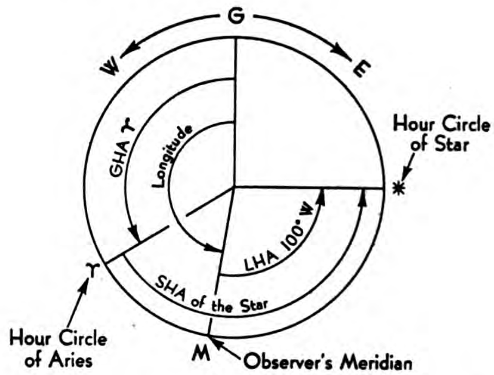


FIG. 86—HOUR ANGLE DIAGRAM FOR STAR

## DEFINITIONS OF ALTITUDE

**True Altitude** ($H_o$)—True altitude is the *arc* of the vertical circle between the celestial horizon and the center of the celestial body. It is also the *angle*, measured at the center of the earth, between the celestial horizon and the center of the celestial body (see Figure 89).

**Sextant Altitude** ($H_s$)—Sextant altitude is the altitude of the celestial body as read on the sextant or octant.

**Computed Altitude** ($H_c$)—Computed altitude is the true altitude of a celestial body as calculated for an assumed position of the observer.

## SEXTANT ALTITUDE CORRECTIONS

**Instrument Correction** (I.C.)—Instrument correction is the correction which must be applied to sextant readings because of mechanical errors in the instrument. (To be discussed more fully in Chapter IX).

**Refraction** (Ref.)—It is a proved principle of physics that light passing from one medium into another of different density is bent from a straight path.

When viewing a distant celestial body, the observer is in reality seeing a ray of light from that body. This ray of light follows a curved path through the earth's atmosphere due to the increasing density of the atmosphere near the



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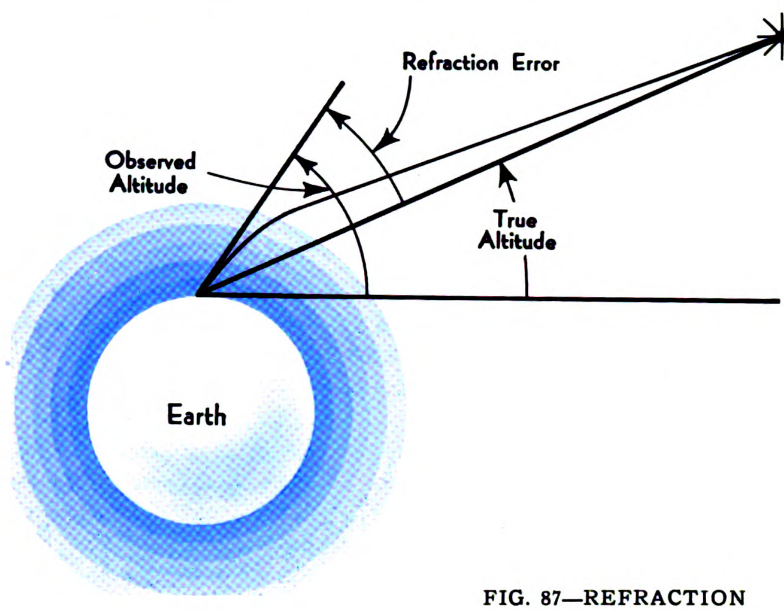


FIG. 87—REFRACTION

surface. In measuring the altitude of a celestial body the observer actually measures the altitude of a line tangent to this curve, and the difference between the last direction of the ray and its direction on entering the earth's atmosphere is the correction angle called *refraction*. Refraction causes the observed altitude ($H_S$) to be always greater than the true altitude ($H_O$), as shown in Figure 87.

Correction for refraction is, therefore, always *minus*. The higher the body, the less the refraction. When the body is directly overhead, refraction is zero. The amount of this correction is tabulated on the back outside cover of the Air Almanac.

**Parallax** (Figure 88)—Parallax may be defined as the angle at the celestial body subtended by the earth's radius.

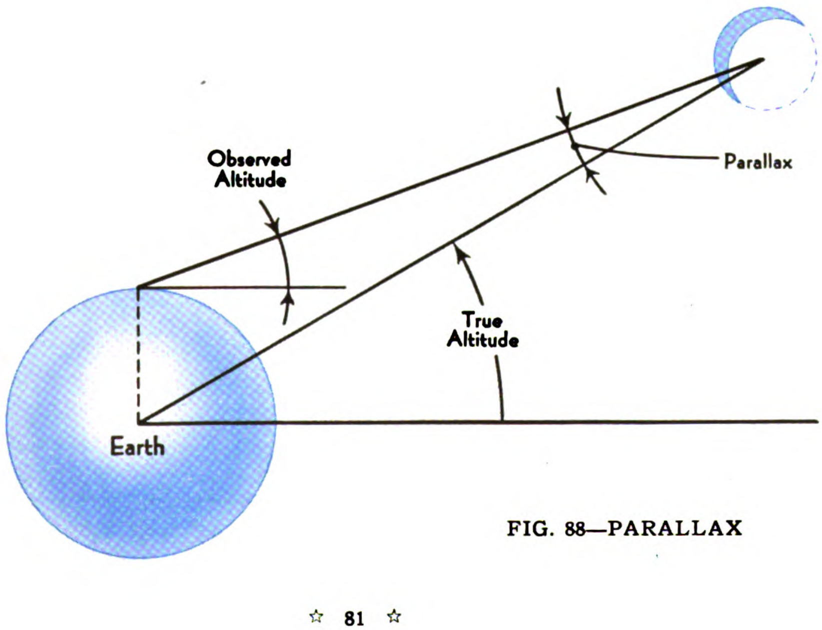


FIG. 88—PARALLAX



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All navigation tables are computed on the assumption that altitude is measured from the center of the earth to the center of the celestial body. However, since the navigator measures the body's altitude from the earth's surface, theoretically a parallax correction must be applied in order to make the true altitude read as though the observer measured it from the center of the earth.

Actually, the moon is the only celestial body whose proximity to the earth makes a parallax correction necessary, all other bodies being so far distant as to make such a correction insignificant for air navigation purposes.

From examination of Figure 88 it is apparent that octant altitude always is less than true altitude. Therefore, correction for parallax always is plus. The amount of correction for various altitudes of the moon may be obtained by inspection from the A.M. side of Air Almanac daily pages. The greater the moon's altitude, the smaller the parallax. When the moon is at zenith, parallax is zero.

**Semidiameter and Dip** (Figure 89)—Semidiameter and dip are altitude corrections seldom applied in aerial navigation, since they are encountered only when using the sea horizon as the horizontal reference plane. They only need to be considered, therefore, when using the marine sextant, or when using an aircraft octant to measure altitude above the sea horizon.

1. **Semidiameter** is the angle at the eye of the observer subtended by the radius of the celestial body. In using the sea horizon the navigator adjusts his octant to cause the upper or lower limb (outside edge) of the reflected image of the sun or moon to just touch (be tangent to) the visible sea horizon. Since the outside edge of the sun or moon is then being used to measure the altitude of the body, instead of the center of the body as required for true altitude, it is necessary to

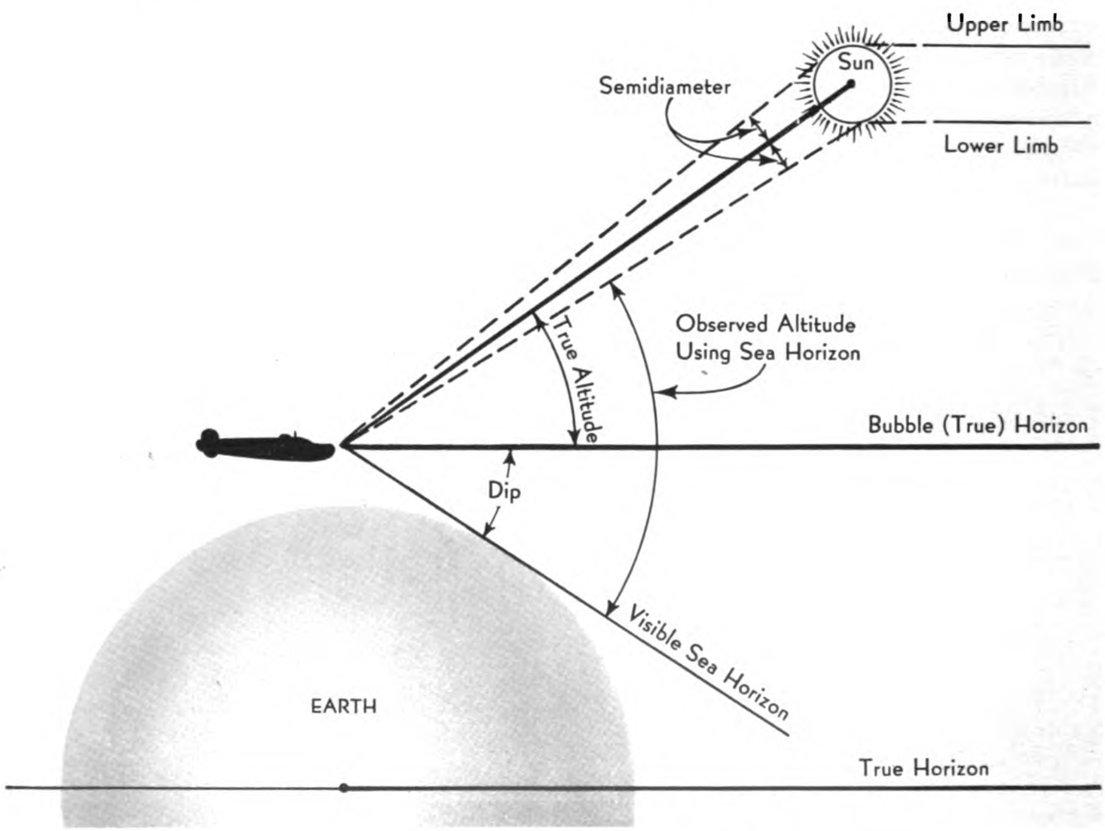


FIG. 89—DIP AND SEMIDIAMETER



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apply a correction equal to half the body's diameter.

The Air Almanac gives the semidiameter correction of the sun or moon on the A.M. side of the daily page. This correction is either plus or minus, depending upon which limb of the body is used to measure the altitude. If the upper limb is used, the correction is minus. If the lower limb is used, the correction is plus.

2. **Dip** is the angle, at the eye of the observer, between the visible sea horizon and the true (celestial) horizon. In Figure 89, it is apparent that the altitude reading, using the visible sea horizon, is always greater than the true altitude; therefore, dip correction is always minus. The amount of correction is tabulated on the back cover of the Air Almanac.

**Examples of Altitude Correction**—On January 1, 1943, the following altitudes were measured with reference to the horizon while flying at an altitude of 8000 feet:

| | *SUN* | PLANET *VENUS* | STAR *ALTAIR* | *MOON* |
|---|---|---|---|---|
| Observed Altitude | 30°20′ | 60°15′ | 20°12′ | 28°35′ |
| Refraction | — 01′ | 00′ | — 02′ | — 01′ |
| Parallax | | | | — 51′ |
| CORRECTED ALTITUDE | 30°19′ | 60°15′ | 20°10′ | 29°25′ |

On January 7, 1943, the following altitudes were measured with reference to the sea horizon while flying at an altitude of 200 feet:

| | (Lower Limb) *SUN* | PLANET *JUPITER* | STAR *RIGEL* | (Upper Limb) *MOON* |
|---|---|---|---|---|
| Observed Altitude | 15°45′ | 60°19′ | 30°55′ | 40°50′ |
| Refraction | — 04′ | — 01′ | — 02′ | — 01′ |
| Parallax | | | | + 44′ |
| Semidiameter | + 16′ | | | — 16′ |
| Dip | — 14′ | — 14′ | — 14′ | — 14′ |
| CORRECTED ALTITUDE | 15°43′ | 69°04′ | 30°39′ | 41°03′ |

## POSITIONS OF PLANETS AND STARS ALONG THE ECLIPTIC

The ecliptic has been defined as the apparent path of the sun on the celestial sphere. Since all of the planets revolve around the sun, it is evident that the path of the planets across the celestial sphere also will follow, very nearly, the ecliptic. Actually, their paths never vary more than eight degrees on either side of the ecliptic.

In the Air Almanac, the diagram on the A.M. side of the daily page represents this path of the sun and planets in the celestial sphere. The sun is shown in the center, and through 180° on either side of the sun are shown the relative positions of the moon, the five planets Mercury, Venus, Mars, Jupiter, and Saturn, and the four bright stars Aldebaran, Antares, Spica, and Regulus (except when they are within five degrees of the sun).

This diagram is useful to the navigator in ascertaining positions of the planets at a glance. For instance, on January 1, 1943, Aldebaran and Saturn are shown in proximity. Recognizing Aldebaran in the sky, the navigator would know that the bright celestial body nearby was Saturn.

## SUNRISE, SUNSET, MOONRISE AND MOONSET

On the P.M. side of the daily page are given tables for finding the times of sunrise, sunset, moonrise and moonset. These are tabulated in terms of local civil time and depend upon the latitude of the observer for correct interpretation.

With the nearest whole degree of the observer's latitude as an argument, the *LCT values* shown opposite the *two nearest tabulated latitudes* are noted and their difference obtained by



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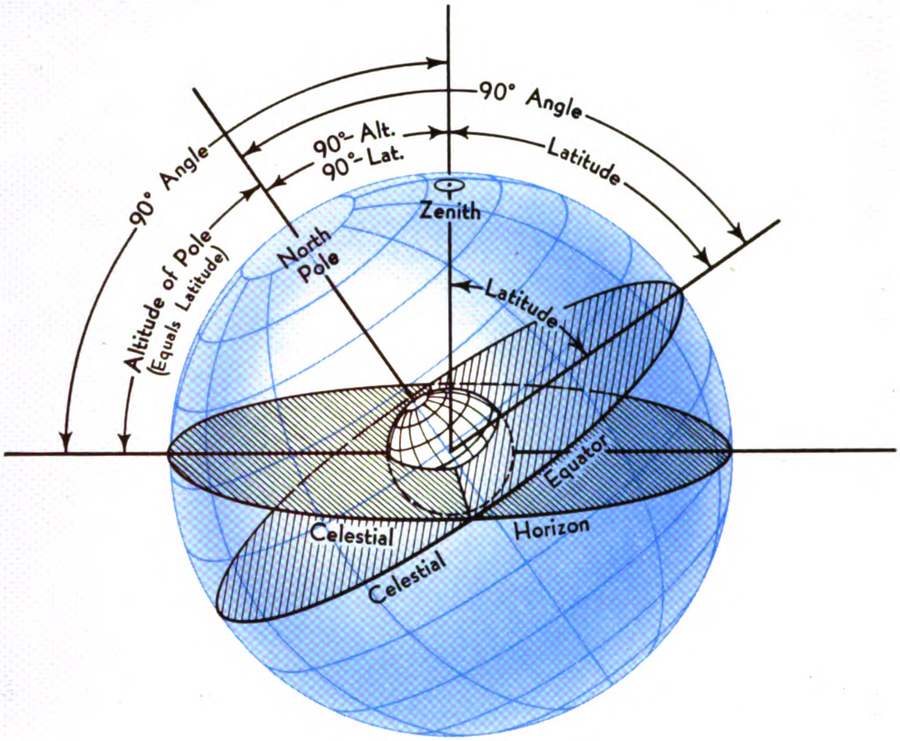


FIG. 90—ALTITUDE OF ELEVATED POLE EQUALS LATITUDE

subtracting the smaller from the greater. The *exact* LCT of the required rising or setting can then be obtained for the observer's latitude by interpolation.

If the GCT is desired (as is usually the case), it can be had by applying the observer's longitude (converted from degrees and minutes of arc to hours and minutes of time) to the LCT.

## LATITUDE BY POLARIS

As shown in Figure 90, the altitude of the elevated pole above the celestial horizon is equal to the observer's latitude. This may be reasoned as follows:

1. Angle between zenith and equinoctial = Latitude.
   Since angle between equinoctial and pole = 90°, and angle between zenith and horizon = 90°, then
2. Angle between zenith and pole = 90° minus alt. pole, or 90° minus latitude.
3. Hence, altitude pole = latitude.

From the diagram in Figure 90, it is apparent that the altitude of a star at the pole would be equal to the latitude. Polaris is known

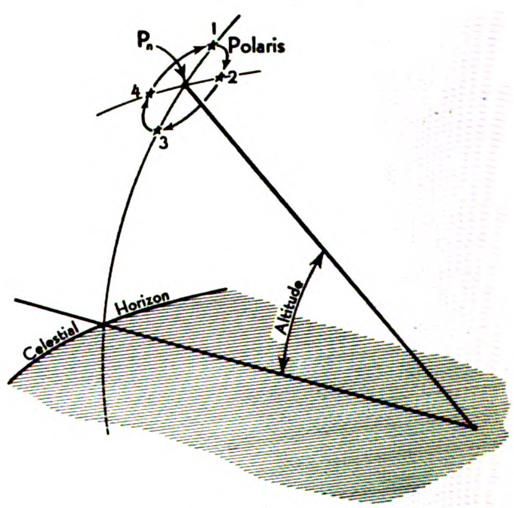


FIG. 91—POLARIS NOT EXACTLY AT $P_n$



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as the North Star. However, it is not located exactly at the pole ($P_n$), but approximately one degree or sixty minutes away. As the earth revolves, the star Polaris appears to revolve around $P_n$ (Figure 91).

When Polaris is in position No. 1 (Figure 90), the altitude of Polaris would be greater than the true altitude of $P_n$. When Polaris is in position No. 2 or No. 4, the altitude of Polaris would be equal to the altitude of $P_n$. With Polaris in any position other than No. 2 or No. 4—such as No. 1 or No. 3—a correction would have to be applied to the true altitude of Polaris to obtain the true altitude of $P_n$, hence the latitude.

The Polaris table in the Air Almanac (located on the back of the star chart) gives the amount of correction to apply to the true altitude of Polaris, in order to find latitude. The tables are computed to give the correction with relation to the local hour angle of the First Point of Aries (LHA ♈) from 0° to 360°, measured to the West.

---

*Example*: On January 1, 1943, at GCT $11^h20^m20^s$, in longitude 145°18′ West, the observed altitude of Polaris—using a bubble horizon—was 32°15′, and the height of aircraft 5000 feet.

| | | | |
|---|---|---|---|
| GCT $11^h20^m$ ........GHA ♈ | 270°14′ | $H_s$ | 32°15′ |
| + For $00^m20^s$ ..........Corr. | 05′ | Ref. | — 01′ |
| GCT $11^h20^m20^s$ .. GHA ♈ | 270°19′ | $H_o$ | 32°14′ |
| Longitude ........................... | 145°18′ West | LHA ♈ Corr. | + 10′ |
| LHA ♈ | 125°01′ West | LATITUDE | 32°24′N |



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**PROBLEM WORK NO. 17**

**GHA AND DECLINATION**

(Find GHA and declination See Appendix for extracts from Air Almanac.)

| No. | DATE | CELESTIAL BODY | GCT | GHA | DECLINATION |
|---|---|---|---|---|---|
| 1 | 5- 1-43 | SUN | 00:17:10 | | |
| 2 | 5- 5-43 | SUN | 22:08:07 | | |
| 3 | 5-10-43 | SUN | 01:00:07 | | |
| 4 | 5-15-43 | SUN | 00:51:17 | | |
| 5 | 5-20-43 | SUN | 17:01:07 | | |
| 6 | 5-30-43 | JUPITER | 18:01:07 | | |
| 7 | 5-15-43 | JUPITER | 14:20:10 | | |
| 8 | 5- 1-43 | JUPITER | 16:20:07 | | |
| 9 | 5-10-43 | JUPITER | 13:24:10 | | |
| 10 | 5-20-43 | JUPITER | 18:08:12 | | |
| 11 | 5-30-43 | MOON | 22:48:30 | | |
| 12 | 5- 1-43 | MOON | 23:00:07 | | |
| 13 | 5-15-43 | MOON | 00:02:07 | | |
| 14 | 5- 5-43 | MARS | 10:06:09 | | |
| 15 | 5-15-43 | MARS | 12:05:00 | | |
| 16 | 5- 1-43 | FOMALHAUT | 09:08:07 | | |
| 17 | 5-10-43 | BETELGEUX | 13:39:07 | | |
| 18 | 5-20-43 | ARCTURUS | 14:17:10 | | |
| 19 | 5-15-43 | DENEB | 08:22:10 | | |
| 20 | 5-30-43 | ALTAIR | 09:05:07 | | |



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**PROBLEM WORK NO. 18**

**HOUR ANGLE DIAGRAMS**

(Find GHA and LHA of the celestial body. Draw hour angle diagrams.)

| No. | DATE | LONGITUDE | CELESTIAL BODY | GCT | GHA ARIES | SHA | GHA BODY | LHA |
|---|---|---|---|---|---|---|---|---|
| 1 | **** | 45°22′W | SUN | **** | | | 300°20′ | |
| 2 | 5-30-43 | 104°15′W | SUN | 10:00:00 | | | | |
| 3 | 5-15-43 | 40°00′E | SUN | 16:23:00 | | | | |
| 4 | 5-15-43 | 170°00′E | MOON | 04:27:23 | | | | |
| 5 | 5-10-43 | 117°11′W | MOON | 08:20:00 | | | | |
| 6 | 5- 5-43 | 105°30′E | MOON | 19:24:00 | | | | |
| 7 | 5- 1-43 | 5°30′E | JUPITER | 18:42:30 | | | | |
| 8 | 5-10-43 | 90°00′W | VENUS | 22:24:00 | | | | |
| 9 | 5-30-43 | 137°27′W | MARS | 06:52:00 | | | | |
| 10 | **** | 15°00′W | DENEB | **** | 260°00′ | | | |
| 11 | 5- 1-43 | 178°50′E | SIRIUS | 04:20:00 | | | | |
| 12 | 5-15-43 | 70°30′W | ALTAIR | 10:20:00 | | | | |
| 13 | 5- 5-43 | 90°05′E | ALDEBARAN | 23:00:00 | | | | |
| 14 | 5-30-43 | 120°23′W | ANTARES | 14:30:00 | | | | |
| 15 | 5-10-43 | 20°15′E | FOMALHAUT | 22:49:00 | | | | |
| 16 | 5-15-43 | 2°15′W | PROCYON | 16:05:00 | | | | |
| 17 | 5- 1-43 | 29°39′E | NUNKI | 02:08:00 | | | | |
| 18 | 5-30-43 | 95°15′W | SPICA | 09:41:00 | | | | |



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**PROBLEM WORK NO. 19**

**OCTANT ALTITUDE CORRECTIONS**

[Correct sextant altitude ($H_S$) to true altitude ($H_O$). Bubble horizon used except where sea horizon is indicated.]

| No. | DATE | CELESTIAL BODY | $H_S$ | ALTITUDE | $H_S$ CORRECTIONS Ref. | Par. | SD | DIP | $H_O$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5- 5-43 | SUN | 49°12′ | 5000′ | | | | | |
| 2 | 5-10-43 | SUN | 57°49′ | 8000′ | | | | | |
| 3 | 5-15-43 | SUN | 36°18′ | 12,000′ | | | | | |
| 4 | 5-20-43 | SUN | 52°42′ | 6000′ | | | | | |
| 5 | 5-25-43 | MOON | 38°16′ | 8000′ | | | | | |
| 6 | 5-10-43 | MOON | 33°38′ | 12,000′ | | | | | |
| 7 | 5- 1-43 | MOON | 29°59′ | 10,000′ | | | | | |
| 8 | 5- 5-43 | MOON | 37°23′ | 9000′ | | | | | |
| 9 | 5-20-43 | RIGEL | 23°19′ | 11,500′ | | | | | |
| 10 | 5-25-43 | CANOPUS | 39°42′ | 2000′ | | | | | |
| 11 | 5- 1-43 | SIRIUS | 41°15′ | 4500′ | | | | | |
| 12 | 5-20-43 | CAPELLA | 27°29′ | 2000′ | | | | | |
| 13 | 5-10-43 | JUPITER | 42°39′ | 8500′ | | | | | |
| 14 | 5-15-43 | SATURN | 35°23′ | 14,500′ | | | | | |
| 15 | 5-25-43 | VENUS | 28°52′ | 8600′ | | | | | |
| 16 | 5-30-43 | JUPITER | 39°17′ | 11,000′ | | | | | |
| 17 | 5- 1-43 | Lower-Limb SUN | 30°42′ | sea horizon 600′ | | | | | |
| 18 | 5-30-43 | Upper-Limb MOON | 45°12′ | sea horizon 800′ | | | | | |
| 19 | 5-30-43 | ALTAIR | 42°21′ | sea horizon 500′ | | | | | |
| 20 | 5-20-43 | SATURN | 41°38′ | sea horizon 100′ | | | | | |



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## PROBLEM WORK NO. 20

## LATITUDE BY POLARIS

(Find latitude.)

| No. | DATE | GCT | Hs | I.C. | ALTITUDE | LONGITUDE | LATITUDE |
|---|---|---|---|---|---|---|---|
| 1 | 5- 1-43 | 19:33:48 | 33°48′ | —15′ | 14,000′ | 117°22′W | |
| 2 | 5- 5-43 | 08:00:12 | 38°00′ | — 8′ | 14,000′ | 133°42′W | |
| 3 | 5-10-43 | 18:32:10 | 36°34′ | —23′ | 14,000′ | 85°23′E | |
| 4 | 5-15-43 | 03:40:00 | 38°43′ | + 3′ | 6000′ | 90°00′W | |
| 5 | 5-20-43 | 17:30:14 | 30°06′ | — 2′ | 10,000′ | 114°00′E | |
| 6 | 5- 1-43 | 11:13:40 | 36°28′ | — 8′ | 5000′ | 178°00′E | |
| 7 | 5- 5-43 | 09:30:14 | 42°20′ | + 1′ | 12,000′ | 118°12′W | |
| 8 | 5-10-43 | 23:30:00 | 25°00′ | — 3′ | 5000′ | 152°40′E | |
| 9 | 5-15-43 | 02:43:19 | 31°14′ | — 7′ | 6000′ | 20°28′W | |
| 10 | 5-20-43 | 17:14:42 | 24°19′ | + 1′ | 10,000′ | 114°26′E | |
| 11 | 5- 1-43 | 02:10:30 | 33°58′ | — 5′ | 8000′ | 117°11′W | |
| 12 | 5- 5-43 | 06:25:10 | 25°42′ | + 5′ | 5000′ | 122°14′W | |
| 13 | 5-10-43 | 03:26:14 | 44°07′ | + 8′ | 10,000′ | 121°14′E | |
| 14 | 5-15-43 | 22:12:30 | 29°56′ | + 1′ | 6000′ | 94°10′W | |
| 15 | 5-20-43 | 20:34:21 | 45°10′ | — 1′ | 14,000′ | 176°41′E | |
| 16 | 5- 1-43 | 14:31:00 | 36°54′ | — 7′ | 9000′ | 69°00′E | |
| 17 | 5- 5-43 | 19:11:23 | 28°04′ | +11′ | 8000′ | 119°32′E | |
| 18 | 5-10-43 | 05:16:13 | 43°11′ | + 3′ | 7000′ | 110°11′W | |
| 19 | 5-15-43 | 11:02:00 | 33°02′ | — 9′ | 11,000′ | 143°21′W | |
| 20 | 5-20-43 | 19:51:29 | 39°55′ | — 4′ | 9000′ | 178°21′E | |



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## CELESTIAL REVIEW EXAMINATION NO. 1

1. Define:

   (a) Altitude
   (b) Equinoctial
   (c) Local Hour Angle
   (d) Azimuth
   (e) Sidereal Hour Angle
   (f) Declination
   (g) Vertical Circle
   (h) First Point of Aries
   (i) Ecliptic
   (j) Sphere

2. Prove with the aid of diagram:

   (a) LHA = GHA — Longitude West
   (b) GHA* = GHA♈ + SHA*

3. Find LHA to nearest whole degree; show solution and diagram.

   (a) May 1, 1943
   Sun
   GCT 08:21:14
   Long. 75°E

   (b) May 10, 1943
   Jupiter
   GCT 20:03:04
   Long. 126°10′W

   (c) May 20, 1943
   Moon
   GCT 17:50:00
   Long. 117°12′E

   (d) May 5, 1943
   Vega
   GCT 04:12:10
   Long. 23°30′W

   (e) May 15, 1943
   Deneb
   GCT 01:19:43
   Long. 100°E

4. Draw the Celestial Sphere showing the following:

   (a) Zenith
   (b) Nadir
   (c) Horizon Coordinates
   (d) Celestial Poles
   (e) Equinoctial Coordinates
   (f) Astronomical Triangle
   (g) Ecliptic
   (h) Vernal Equinox



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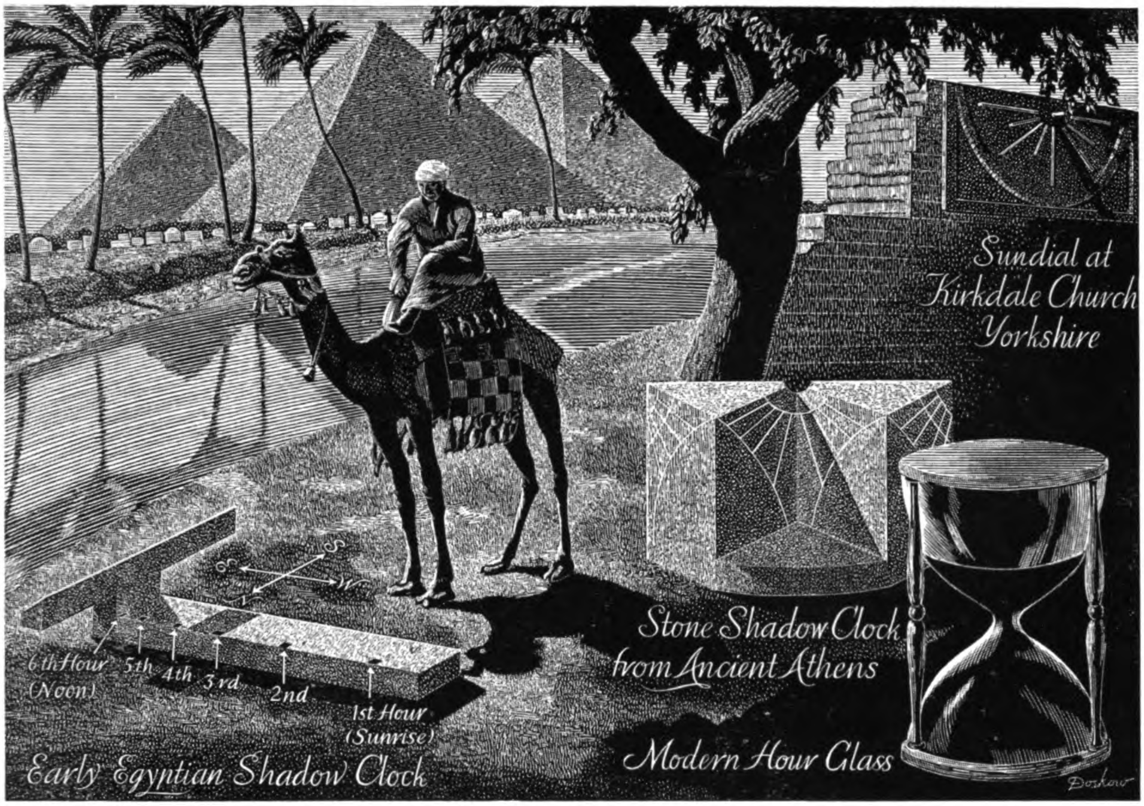


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# TIME

THE navigator's concept of time differs radically from that held by the average citizen. To the man on the street, time affords a method of determining the beginning and end of a working day, or aids him in keeping an appointment. To be "on time" means, to the citizen, to arrive at his destination within a few minutes of the predetermined moment.

But the navigator has a deeper respect for time. "On time" to him means, literally, on time to the very second if possible, for a variance of seconds in his timekeeping will result in a miscalculation—perhaps a dangerous one—of his position.

Celestial navigation involves knowing, at any instant, the exact location in the celestial sphere of all important celestial bodies with relation to the prime meridian of Greenwich. Lacking the exact time, the navigator would be unable to determine the exact location of these bodies. It follows, then, that he would be unable to determine the exact location of his aircraft, for his location is determined by reference to the position of these celestial bodies.

**Definition**—Time may be defined as a measure of duration, or the elapsed interval between two events.

**Measurement of Time**—A measure of time is afforded in the daily rotation of the earth on its axis, by observing the elapsed interval between two successive apparent transits of the sun or a star over a given terrestrial meridian



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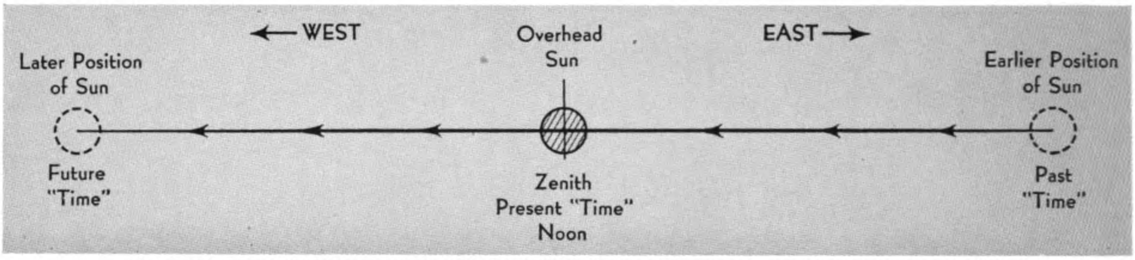


FIG. 92—APPARENT MOVEMENT OF SUN AFFORDS MEASURE OF TIME

(Figure 92). Although any meridian may be used, by international agreement the meridian through the Naval Observatory at Greenwich, England, was chosen as the prime meridian from which to reckon time.

**Transit Instrument**—Time is recorded at the observatory by a transit instrument. Basically, this instrument is a tube, the longitudinal axis of which is aligned with the meridian and the upper end of which contains a series of threads, parallel to the meridian. The lower end contains photographic equipment, which automatically photographs, on a moving plate, the exact instant that the celestial body chosen crosses the meridian (Figure 93).

**Note:** 1. The location of a celestial body West of Greenwich is determined by Greenwich hour angle.

2. The location of an observer either East or West of Greenwich is determined by longitude.

3. The location of a celestial body in relation to the observer is determined by local hour angle.

**Relationship of Time, Hour Angle and Longitude** (Figure 94)—GHA, LHA, and longitude are measured in degrees of arc along the equinoctial or equator, which are great circles equal to 360° of arc.

Time also may be converted into degrees of arc, because the unit of time (one day) is generated by the apparent movement of a body, in a circle of 360° of arc, around the earth. Therefore, time, hour angle, and longitude are related directly to each other.

Time may be converted into degrees of arc (hour angle or longitude), or arc (hour angle or longitude) may be converted into time by division or multiplication.

**Conversion of Time Into Arc**—The unit of time (one day) is divided into 24 hours of 60 minutes each, and each minute equals 60 seconds.

Since one day of 24 hours equals 360° of arc, the division of 360° by 24 hours proves that one hour equals 15° of arc.

Thus: One minute $= \frac{1}{4}°$ (or 15′) of arc.
Four minutes = 1° of arc.
One second $= \frac{1}{4}'$ (or 15″) of arc.
Four seconds = 1′ of arc.

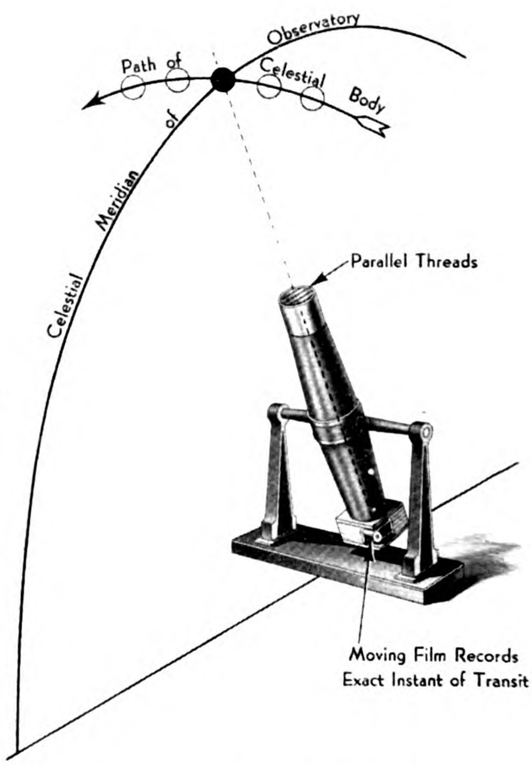


FIG. 93—OPERATION OF TRANSIT INSTRUMENT



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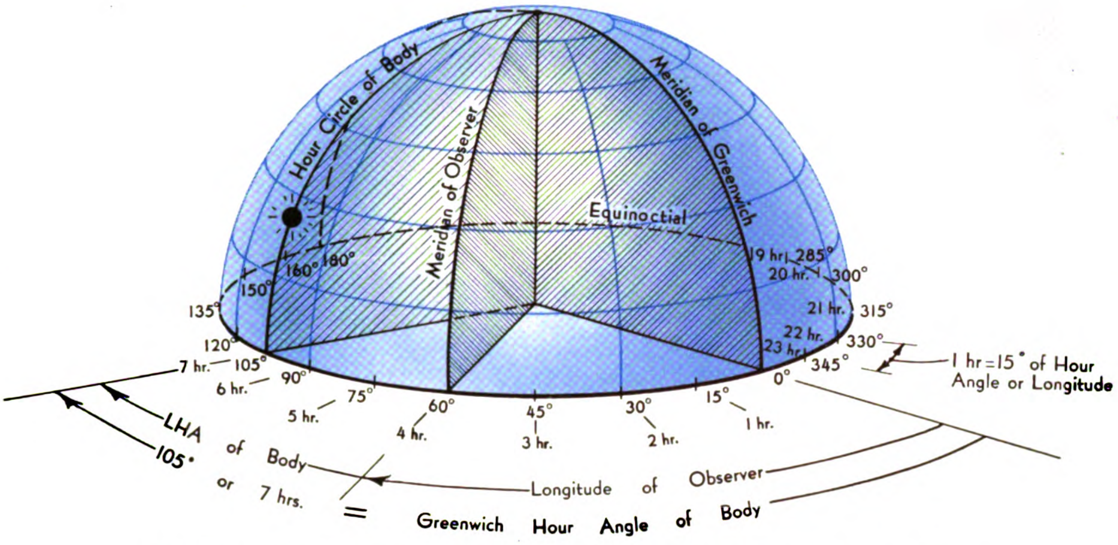


FIG. 94—RELATIONSHIP OF TIME, HOUR ANGLE, AND LONGITUDE

**Three Kinds of Time**—In addition to its daily rotation on its own axis, the earth also is describing a yearly revolution around the sun. The path it follows in this revolution is known as the earth's orbit. This *real* movement of the earth gives rise to an *apparent* movement of the sun. But since the earth does not move at a constant rate along its orbit, the apparent motion of the sun is not uniform, nor does it correspond exactly to the apparent movement of the stars. This variation in apparent movement gives rise to three kinds of time:

1. Apparent solar time, the unit of which is one apparent day.

2. Mean time or civil time, the unit of which is one civil day.

3. Sidereal time, the unit of which is one sidereal day.

## APPARENT SOLAR TIME

**Measurement** — Apparent solar time is measured by the daily motion of the true sun.

**The Unit** — One apparent day is the interval of time between two successive *lower transits* of the sun over the same meridian. Obviously, the sun actually would have to be over the upper branch of the observer's meridian in order to measure the exact instant of transit. However, the unit, one day, containing twenty-four hours, is considered to have commenced twelve hours earlier, or at the instant the sun crossed the lower branch of the meridian, at midnight. What actually is measured is *apparent noon* (Figure 95). Thus, time and hour angle differ by twelve hours, as hour angle is measured from the *upper* branch of the meridian.

**Variation in Apparent Time**—Clocks cannot be regulated to apparent solar time because the unit, one solar day, varies in length from day to day. This unequal rate is due to the obliquity of the ecliptic, and the lack of uniformity of motion of the earth in its orbit.

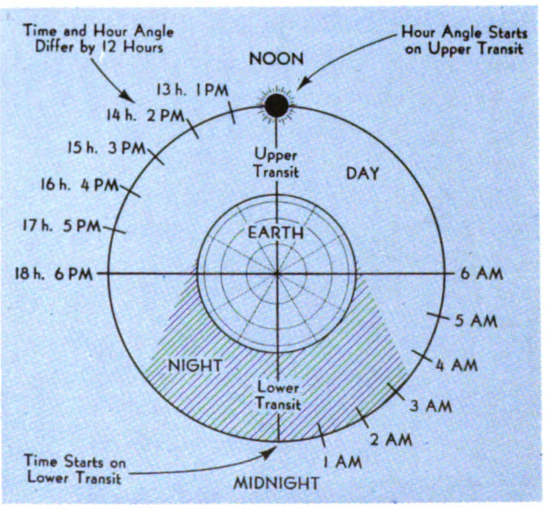


FIG. 95—UPPER AND LOWER TRANSITS OF SUN



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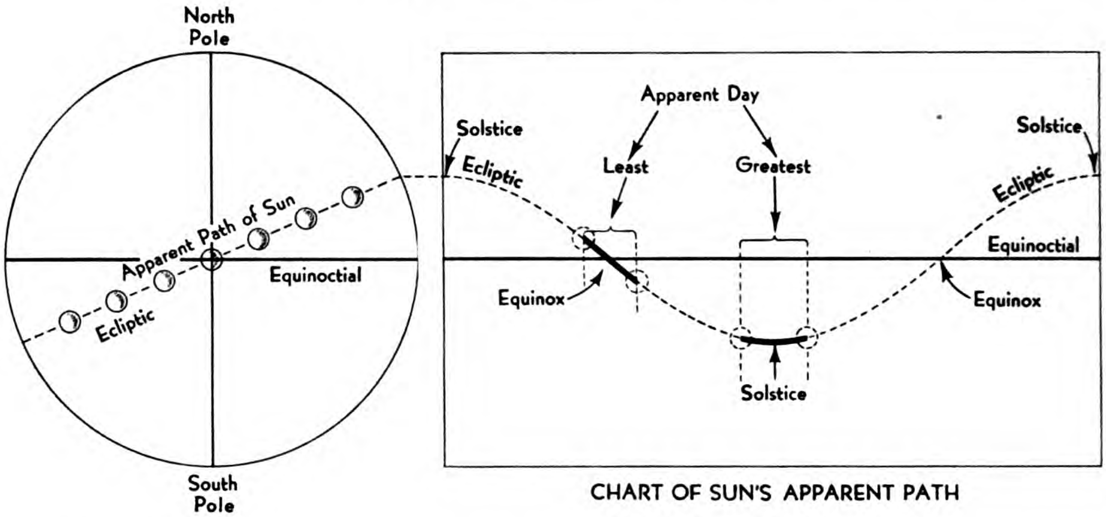


CHART OF SUN'S APPARENT PATH

FIG. 96—VARIATION IN LENGTH OF APPARENT DAY DUE TO OBLIQUITY OF ECLIPTIC

**Obliquity of the Ecliptic** — Uniform time and hour angle are measured on the equinoctial. However, the apparent path of the sun is along the ecliptic, which is inclined at an angle of 23°27'30" to the equinoctial. Hence, when the sun's motion is translated to the equinoctial, each apparent day varies in length (Figure 96).

Because of the angle of the apparent sun's path on crossing the equinoctial, the apparent day intercepts a smaller arc of equinoctial at the equinoxes than at the solstices, where the apparent path is parallel to the equinoctial.

**Lack of Uniformity of Motion of the Earth in Its Orbit**—In its yearly movement around the sun, the earth describes an ellipse. It has been demonstrated by Kepler's second law that in December, when the earth is closest to the sun (91,300,000 miles), the earth travels at a greater rate than when farthest away in July (94,000,000 miles). This uneven rate of travel of the earth causes the apparent motion of the sun to vary (Figure 97).

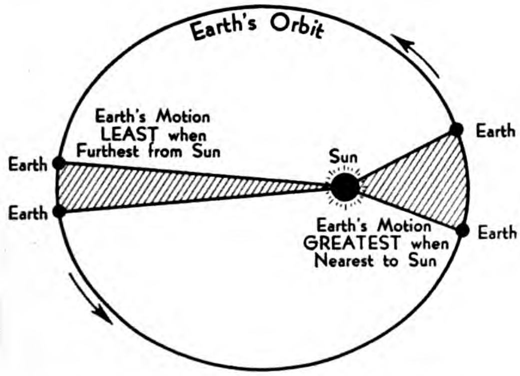


FIG. 97—EARTH'S RATE OF MOTION NOT UNIFORM

## CIVIL TIME OR MEAN SOLAR TIME

**Description**—Civil life is mainly dependent on the hours of daylight. Therefore, the sun is the most logical reference point for measuring civil time. But since clocks cannot be regulated to the apparent sun's motion, a fictitious body called the *mean sun* is assumed to move along the equinoctial at a uniform daily rate, equal to the average rate of the *true sun* along the ecliptic.

**Measurement**—Civil time, or mean time, is measured by the daily motion of the mean sun.

**Unit**—One civil day is the interval of time between two successive lower transits of the mean sun over the same meridian. Clocks are regulated to civil time because it is uniform. Clocks used in civil life usually divide the day of 24 hours into two parts of 12 hours each. The 12-hour period measured from the instant of lower transit of the mean sun is called A. M. time, and the 12-hour period measured from the instant of upper transit is called P. M. time.



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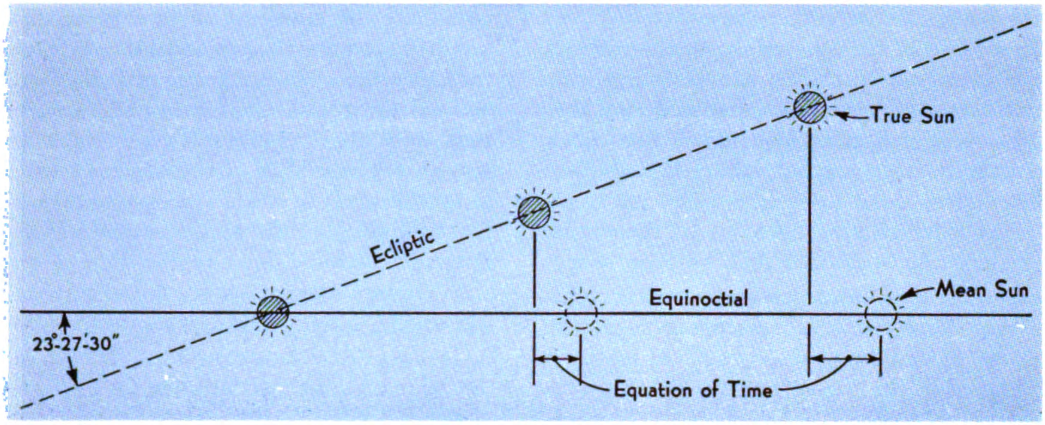



**FIG. 98—RELATIONSHIP OF MEAN TIME TO SOLAR TIME**

Chronometers used in navigation, however, usually are equipped with a 24-hour dial.

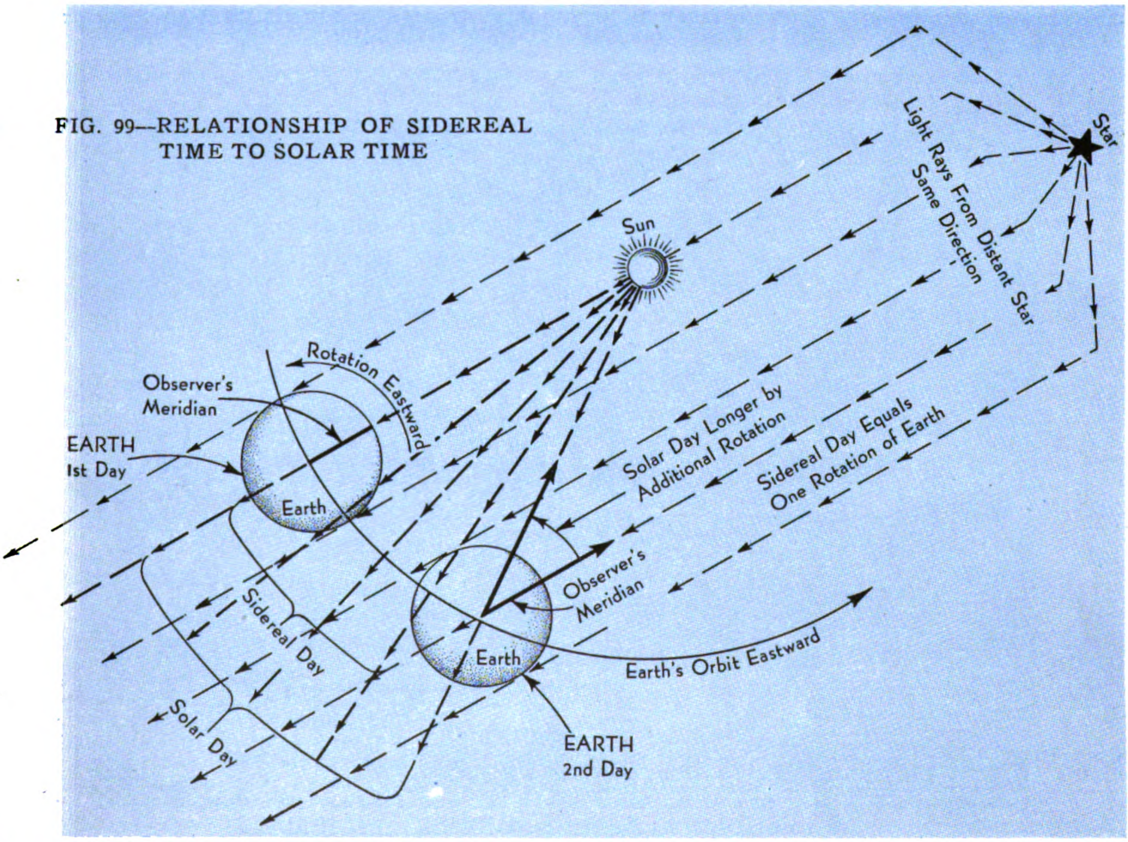
**Equation of Time**—The equation of time is the difference in hour angle between the hour circle of the true sun and the hour circle of the mean sun (Figure 98). The true sun sometimes is ahead and sometimes behind the mean sun by an amount which varies from zero to about 16 minutes.

## SIDEREAL TIME

**Measurement** — Sidereal time is derived from the apparent movement of the stars.

**Unit**—One sidereal day is the interval of

**FIG. 99—RELATIONSHIP OF SIDEREAL TIME TO SOLAR TIME**



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time between two successive upper transits of the First Point of Aries over the same meridian. (The First Point of Aries, as previously defined, is one of two points of intersection of the ecliptic and equinoctial. Although it is a computed point in the celestial sphere invisible to an observer, it was selected as the point of origin for sidereal time because, in theory, it moves along the equinoctial at a uniform rate.)

Since the sidereal day starts at the instant the First Point of Aries crosses the upper branch of a meridian, sidereal time and the hour angle of the First Point of Aries are equivalent.

**Difference Between Sidereal and Solar Time** (Figure 99)—Units of sidereal time are of less duration than corresponding units of solar time because the sidereal day is measured from a star, whose distance is so infinitely great it may be considered a fixed point in space. By comparison, the solar day is measured from the sun, which appears to move due to the earth's yearly revolution around the sun.

Since stars are fixed, the sidereal day is generated solely by the earth's rotation, which is equal to approximately $23^h56^m$ of a mean solar day. A mean solar day is nearly four minutes greater than a sidereal day because each day the earth moves in its orbit approximately 4° around the sun. Therefore, before two successive transits of the sun can be observed, the meridian of the observer will have to perform more than one complete rotation, corresponding to the apparent daily change in the sun's position.

The complete orbit covered by the sun is a mere pin point in comparison with the infinite distance of the nearest star. Therefore, the direction of a star is the same for any position of the earth in its orbit.

## ZONE TIME

**Description**—The civil day for any position on the earth starts at the instant the mean sun crosses the lower branch of the meridian of that place. Therefore, *civil time* varies with the longitude of the place.

For convenience, and also in order to avoid endless confusion when traveling or in everyday business life, the entire region—as near as practical—extending 7½° of longitude on either side of a designated standard meridian

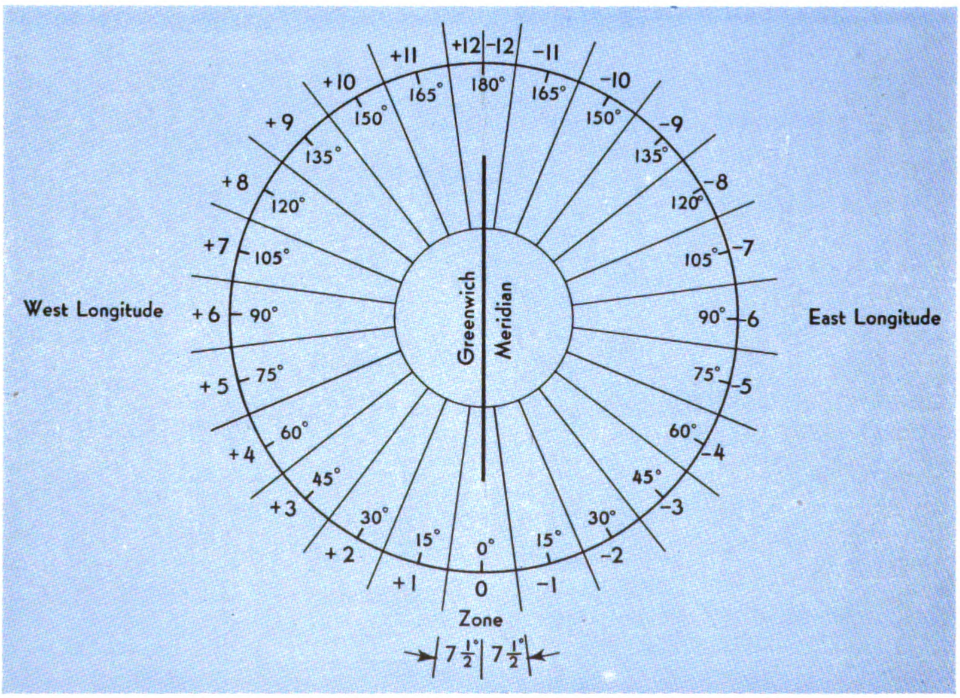


FIG. 100—DERIVATION OF ZONE DESCRIPTIONS



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keeps its watches set to the time of the standard meridian. This time is called *zone time.*

The $7\frac{1}{2}°$ of longitude on either side of the standard meridian form a zone 15° wide which equals the number of degrees of longitude the mean sun appears to travel in one hour. In order to develop zone time, the surface of the earth is considered to be divided into 24 of these one-hour zones, and the 24 standard meridians (15° of longitude apart) commence with the meridian of Greenwich as the prime meridian for reckoning time and longitude.

**Zone Description** (ZD) (Figure 100)—Zone description, abbreviated ZD, is the number of hours the zone is located East or West of the prime meridian of Greenwich. The twelve zones west of Greenwich are considered plus, and the twelve zones East of Greenwich, minus.

The zones in *West longitude* are called *plus zones* because, when an aircraft is in West longitude, the Greenwich civil time is *greater* than the local zone time, hence the ZD must be *added* to the *zone time* to find the GCT. This is due to the apparent westward movement of the sun. When the sun is on the Greenwich meridian it has not yet crossed the meridians West of Greenwich, but it already has crossed the meridians East of Greenwich. As a result, when an aircraft is in *East longitude,* the Greenwich civil time is *less* than the local zone time and the zones are called *minus* zones, which means that the ZD must be *subtracted* from *zone time* to get the GCT (Figure 100).

**International Date Line**—The lower branch of the Greenwich meridian is known as the International Date Line, because an observer crossing this meridian will experience a date change.

Since zones extending to the West of Greenwich increase progressively to plus 12 hours, and zones East of Greenwich to minus 12 hours, obviously where they meet (at the lower branch of the Greenwich meridian) there exists an accumulated time difference of 24 hours or one day. An observer crossing from the plus 12 (West) zone into the minus 12 (East) zone would, therefore, gain one day. Conversely, crossing from East to West, he would lose one day.

---

**Zone Time Conversion**—If either the zone time or the Greenwich civil time is known, the other is easily computed by the following jingle:

Longitude West—Greenwich Time Best.
Longitude East—Greenwich Time Least.

*Example* No. 1

May 1, Longitude 75° West, Zone Time 10:20 A. M.
Find: GCT.

$$\frac{\text{Longitude } 75° \text{ West}}{15° \text{ (one hour longitude)}} = +5 \text{ hours} = \text{Zone Description}$$

Zone Time = 10:20 A. M.
ZD = +5:00
GCT 15:20 (Greenwich Time Best)

*Example* No. 2

May 1, Longitude 90° East, GCT $20^h30^m00^s$
Find: Zone Time.

$$\frac{\text{Longitude } 90° \text{ East}}{15°} = -6 \text{ hours} = \text{Zone Description}$$

GCT = 20:30:00 (Greenwich Time Least; there-
ZD — 6:00:00 fore, ZD —6 hours is added
Zone Time 26:30:00 to GCT)
—24:00:00
Zone Time = 2:30 A.M. May 2



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**LCT-GCT Relationship—**As discussed previously, civil time is time based on the apparent passage of the mean sun over the lower branch of a meridian on the earth. If the Greenwich meridian is used, the result is GCT. If any meridian other than the Greenwich meridian is used, the result is known as local civil time. Since the relationship between any meridian on the earth and the Greenwich meridian is determined by longitude, it is logical to assume—as is actually the case—that LCT and GCT also are related by longitude. In other words, the local civil time for any meridian, at any given instant of time, differs from Greenwich civil time by the longitude of that meridian. This may be expressed as follows:

GCT = LCT + West Longitude, or
— East Longitude.

Conversely,

LCT = GCT — West Longitude, or
+ East Longitude.

The above formulas may be used to determine either LCT or GCT if one of them, and the longitude, is known. Or, if both the LCT and GCT are known, then it is possible to solve for the longitude. Obviously, however, consistent terms must be used. If solving for time, then longitude must be converted from arc to time; if solving for longitude, then the difference between LCT and GCT must be converted to degrees of arc.

It is important to recognize that zone time is, in reality, no more than a special case of local civil time, the distinction being that in zone time, the entire area lying $7\frac{1}{2}^\circ$ on either side of a standard meridian uses the local civil time of that standard meridian as its time. Actually, every point within the area has its own local civil time. Thus the zone time of a place whose longitude is 16° is one hour different than the GCT, whereas its LCT differs from the GCT by one hour and four minutes, which represents the exact longitude of the place converted from arc to time.

---

Examples of LCT and GCT Problems:

*Example* No. 1

May 1, Longitude 83°30′ West, LCT = 6:32 A. M.

Find: GCT.

Longitude 83°30′ West, converted to time = $5^h34^m$

$$\left(\frac{75^\circ}{15} = 5^h\right) + (8^\circ \times 4^m = 32^m) + (30' \times 4^s = 120^s \text{ or } 2^m) = 5^h34^m$$

LCT = $6^h32^m$
Longitude = $5^h34^m$ West
GCT = $12^h06^m$ (Longitude West—GCT Best)

*Example* No. 2

May 1, Longitude 83°30′ East, GCT = $16^h20^m10^s$

Find: LCT.

Longitude 83°30′ East, converted to time = $5^h34^m$

GCT = $16^h20^m10^s$
Long. 5°34′ 00″ East
LCT = $21^h54^m10^s$ or $9^h54^m10^s$ P. M. (Longitude East —GCT Least)



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## PROBLEM WORK NO. 21

## LOCAL ZONE TIME

(Find arrival time and date in GCT and local zone time.)

| No. | FROM | TO | DEPARTURE (GCT) | FLYING TIME | ARRIVAL TIME AND DATE | |
|---|---|---|---|---|---|---|
| | | | | | GCT | ZONE TIME |
| 1 | San Francisco | Honolulu | 10:00 May 1 | $12^h00^m$ | | |
| 2 | Canton | Honolulu | 21:00 May 5 | $9^h00^m$ | | |
| 3 | Christmas | Fiji | 14:00 May 10 | $7^h00^m$ | | |
| 4 | New Caledonia | Brisbane | 11:00 May 15 | $6^h30^m$ | | |
| 5 | Brisbane | New Caledonia | 23:00 May 20 | $6^h00^m$ | | |
| 6 | Fiji | Canton | 10:30 May 25 | $8^h15^m$ | | |
| 7 | Honolulu | San Francisco | 23:00 May 30 | $13^h00^m$ | | |
| 8 | Honolulu | Christmas | 14:15 May 15 | $10^h00^m$ | | |
| 9 | Christmas | Fiji | 15:00 May 1 | $7^h00^m$ | | |
| 10 | Fiji | New Caledonia | 16:30 May 10 | $6^h00^m$ | | |
| 11 | New Caledonia | Brisbane | 09:00 May 5 | $6^h30^m$ | | |
| 12 | Brisbane | New Caledonia | 06:30 May 20 | $5^h30^m$ | | |
| 13 | New Caledonia | Fiji | 17:15 May 25 | $7^h00^m$ | | |
| 14 | Fiji | Canton | 16:00 May 15 | $7^h00^m$ | | |
| 15 | Canton | Honolulu | 07:00 May 30 | $11^h00^m$ | | |
| 16 | Honolulu | San Francisco | 14:30 May 1 | $13^h00^m$ | | |
| 17 | San Diego | Honolulu | 05:13 May 5 | $13^h41^m$ | | |
| 18 | San Francisco | San Diego | 22:00 May 10 | $3^h00^m$ | | |

ZONE DESCRIPTION (War Time)

| | | | |
|---|---|---|---|
| Brisbane | —10 | Christmas Is. | +10½ |
| San Francisco | + 7 | Fiji Islands | —12 |
| Honolulu | + 9½ | New Caledonia | —11 |
| Canton Island | +10½ | San Diego | + 7 |



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## PROBLEM WORK NO. 22

### LCT—GCT

(Find missing LCT or GCT, and date to nearest second.)

| No. | LONGITUDE | GCT TIME | GCT DATE | LCT TIME | LCT DATE |
|---|---|---|---|---|---|
| 1 | 90° W | 22:30:20 | May 1 | | |
| 2 | 15° E | 04:16:00 | May 5 | | |
| 3 | 110°15′W | 05:55:00 | May 10 | | |
| 4 | 178°30′E | 23:45:30 | May 15 | | |
| 5 | 117°11′W | 16:43:04 | May 20 | | |
| 6 | 3°15′E | 09:20:20 | May 25 | | |
| 7 | 145°30′W | 08:25:30 | May 30 | | |
| 8 | 90°15′E | 18:29:00 | May 10 | | |
| 9 | 170°16′E | 09:05:06 | May 1 | | |
| 10 | 116°14′E | 18:42:00 | May 15 | | |
| 11 | 173°40′W | | | 06:40 P. M. | May 5 |
| 12 | 162°10′E | | | 05:10 P. M. | May 1 |
| 13 | 93°20′E | | | 12:42 P. M. | May 10 |
| 14 | 46°30′E | | | 10:00 A. M. | May 15 |
| 15 | 73°40′W | | | 07:56 P. M. | May 20 |
| 16 | 117°11′W | | | 04:53 P. M. | May 25 |
| 17 | 173°20′E | | | 12:00 Noon | May 30 |
| 18 | 45°00′W | | | 02:16 P. M. | May 15 |
| 19 | 168°10′W | | | 11:41 P. M. | May 5 |
| 20 | 101°11′E | | | 01:32 A. M. | May 20 |



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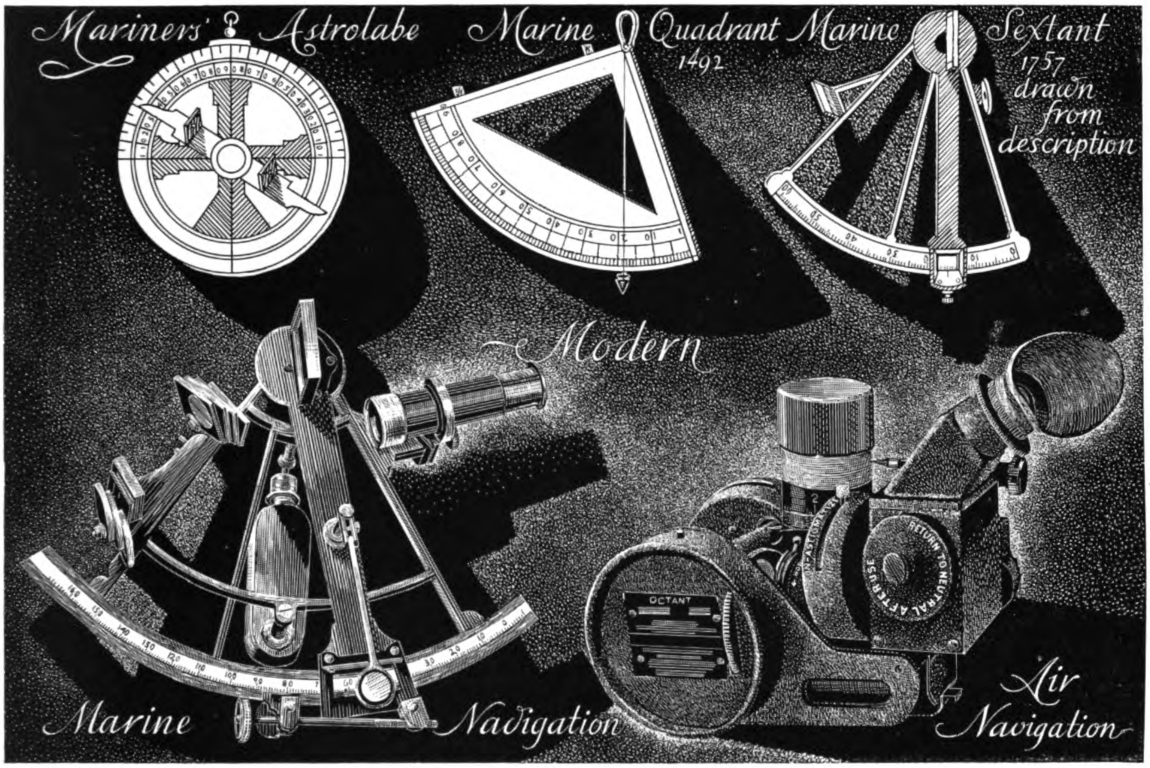


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# AIRCRAFT OCTANT

LIKE the modern aircraft compass, which is an up-to-date version of the medieval mariners' lodestone, today's aircraft octant is essentially a refinement of the early altitude-measuring devices used by such famed navigators as Columbus and Vasco de Gama. Columbus knew little of the science of celestial navigation as it is practiced today. History indicates that he relied almost exclusively upon dead reckoning, at which he was unusually proficient considering the crudeness of methods employed.

According to historians, the common quadrant was the only instrument of celestial navigation Columbus ever used. This primitive device was a quarter-circle of wood with sights along one edge. A weight, swung from the apex of the instrument by a silk cord, caused the cord to give an altitude reading on the 90° scale when the sights were lined up on the heavenly body observed. It is easy to imagine the difficulties these early navigators encountered when trying to use such a device on their small, rolling, pitching ships. In fact, it is thought that Columbus never employed the quadrant for navigation, using it solely in attempts to determine the position of islands and other areas discovered in his journeys. Vasco de Gama, too, was equipped with some sort of altitude-measuring device, thought to be an astrolabe, and it is said that he always disem-



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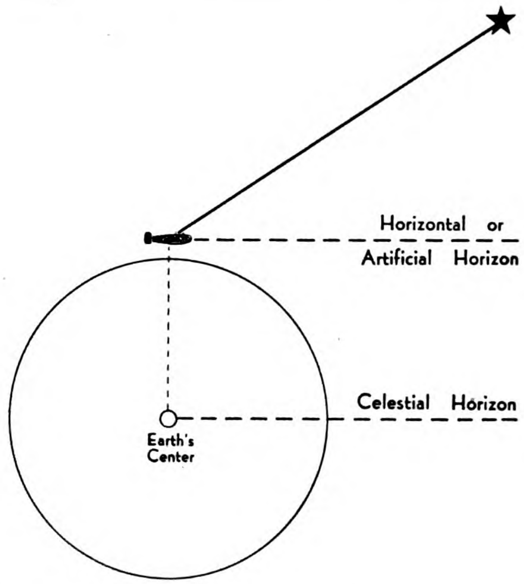


FIG. 101—OCTANT EMPLOYS ARTIFICIAL HORIZON

barked and hung the instrument on a tree in order to secure a steady rest when taking altitude sights.

The term "sextant" (sixth of a circle) first was applied to an optical instrument for measuring angular distances, invented by John Hadley in 1731. Hadley's device actually was an octant (eighth of a circle), but his instrument was enlarged by a Capt. Campbell in 1757 to one-sixth of a circle to meet the needs of navigation.

The marine sextant used for navigation of surface vessels is, generally speaking, not practical for aerial navigation since it relies upon a visible horizon from which to measure the altitude of a celestial body. Such a horizon seldom is available to the aerial navigator, and he must, therefore, use an instrument which contains its own horizon. For this reason the bubble octant was developed. Conversely, the bubble octant is seldom useful on surface vessels because results obtained with it are not considered sufficiently accurate for surface navigation purposes.

## OCTANT OR SEXTANT

The aircraft octant, or sextant, is an instrument for measuring the angle between any two visible objects. The principal use of the octant in aerial navigation is for measuring the altitude of a celestial body above an artificial horizon (a horizontal plane parallel to the celestial horizon) and in some cases, the altitude of a body above sea horizon (See Figure 101).

The terms "octant" and "sextant" are derived from the size of the angle such instruments are capable of measuring (Figure 102).

An octant measures angles up to 90°.
A sextant measures angles up to 120°.
A quintant measures angles up to 144°.
A quadrant measures angles up to 180°.

Most aircraft instruments are of the octant type, as the aerial navigator seldom has reason to measure an angle over 90°. A few, however, are of the sextant type.

## ACCURACY OF AIRCRAFT OCTANTS

Obviously, it is impossible to measure exactly the altitude of a celestial body. The accuracy of measurement depends upon the refinement of the measuring instrument.

The theodolite, a high-precision instrument used in surveying, can measure angles as small as 1/1000th of a minute of arc.

A marine sextant, using the visible sea horizon, will measure altitude accurately to within tenths of a minute. Aircraft octants, however, which are made light and compact for easy handling, can be relied upon only to measure an altitude, from the sea horizon, to within one or two minutes, and when the artificial horizon is used, measurements may contain inaccuracies of from four to eight minutes or more.

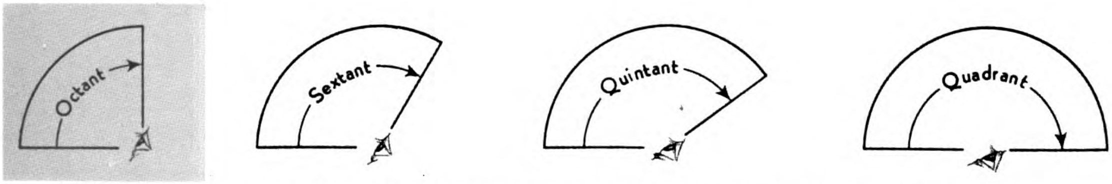


FIG. 102—ALTITUDE RANGE DETERMINES NAME OF INSTRUMENT



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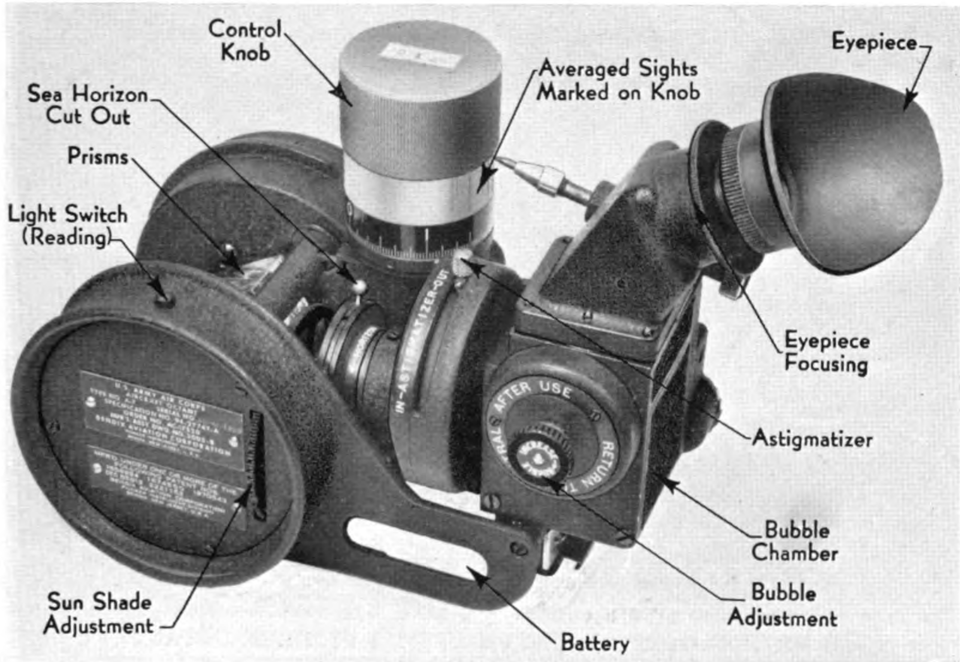


Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

**FIG. 103—BUBBLE OCTANT (Pioneer averaging type)**

## TYPES OF OCTANTS

**Reasons for Different Types of Octants—** The ideal aircraft octant would be one which could be used to measure, with consistent accuracy, the altitude of a celestial body with a single observation.

This ideal is nearly accomplished when the altitude of a celestial body is measured with reference to the sea horizon. However, the sea horizon seldom is visible to the aerial navigator, and even when it is, it can be used only if the aircraft is at a very low altitude. Hence it is necessary, in aerial navigation, to employ an instrument which will measure the altitude of celestial bodies above an artificial horizon parallel to the true or celestial horizon.

The necessity of using an instrument which will measure accurately the altitude of a celestial body above an artificial horizon presents the main problem in present-day aerial navigation, and is the reason why so many different types of aircraft octant have been developed. Principal types which thus far have been developed are the gyro, pendulus, and bubble octants. Each of these utilizes the gravitational pull of the earth on a gyro, pendulum or bubble in order to produce artificially a true horizon.

**Gyroscopic Octant —** The gyroscopic-type octant produces a true horizontal by means of a rotating gyro. This instrument appears to have possibilities of attaining the "single observation" ideal, but thus far no such instrument has been developed for aerial navigation which is adaptable from the standpoint of size, weight, and structural ruggedness.

**Pendulus Octant—**The pendulus-type octant produces a horizontal by means of a pendulum. No octant of this type has yet been developed suitable for aerial navigation.

**Bubble Octant** (Figure 103)—The bubble-type octant produces a horizontal by means of the gravitational pull on an air bubble, which is either permanently formed, or formed prior to use, in an enclosed chamber of liquid.

Nearly all aircraft octants are of the bubble horizon type, principally because of their simple and rugged construction, and ease of handling.

There are many bubble-type octants in use, and the aerial navigator should become familiar with as many of them as possible. Nearly all



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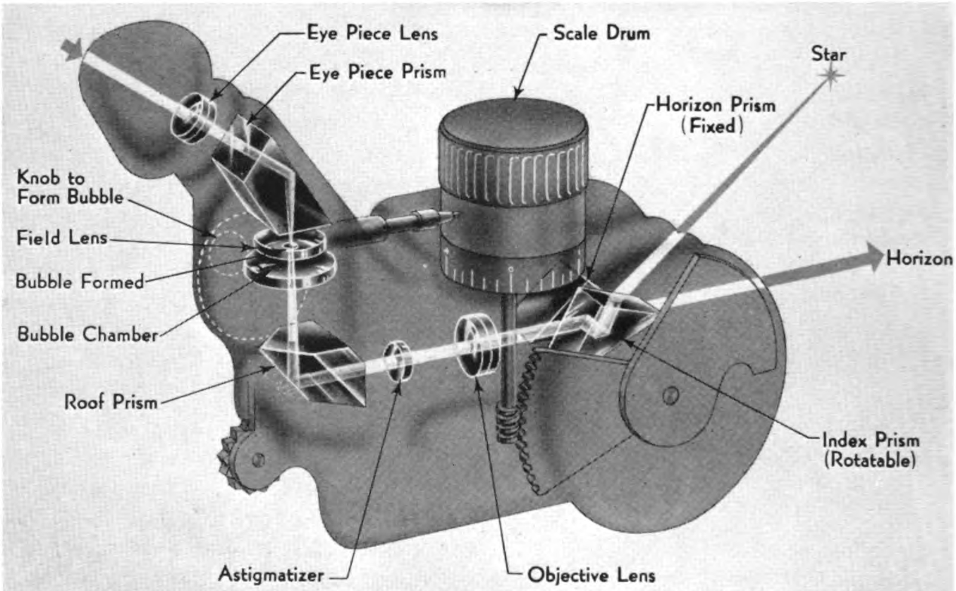


Courtesy Eclipse Pioneer Division Bendix Aviation Corporation.

**FIG. 104—OPTICAL SYSTEM OF THE PIONEER OCTANT**

types now available are reliable when used correctly and handled with care. In choosing an octant, the navigator should ascertain if the instrument is constructed strongly enough to give consistently accurate readings under normal handling conditions. He also should consider the reliability of its bubble horizon, size and weight of the instrument, and most importantly, the ease with which it can be used to determine altitudes. The best type octants incorporate a simple and accurate averaging device, and allow a clear view of the sky so that the navigator can be certain he has the correct star in his field of vision. Another important consideration in the octant is the ease with which any error in the instrument can be determined and eliminated. An added help in the instrument is a means of observing the sea horizon, to permit check of index error while in flight (the procedure for which is explained later in this chapter).

## OPTICAL PRINCIPLE OF OCTANTS

The principle underlying the operation of all altitude-measuring devices is essentially the same. A law of physics states that when a ray of light is reflected from a plane surface, the "angle of incidence" is equal to the "angle of reflection."

In the octant, the angle between a celestial body and the horizon (either the sea horizon or a self-contained artificial horizon) is measured by bringing into coincidence, at the eye of the observer (by means of an optical system consisting of prisms, lenses, and mirrors), the rays of light received directly from one, and by reflection from the other. The angle between the celestial body and horizon (altitude) then is read on a graduated scale by means of a counter (indicator), actuated by the movement of the reflecting surfaces.

Figure 104 illustrates the principle of the Pioneer Octant. The index prism reflects a ray of light to the observer's eye. The horizon prism is fixed and through it the horizon may be viewed directly. Normally, however, an artificial horizon, indicated by the bubble, is used. In this type of bubble octant the image of a celestial body is made to coincide with the bubble. In some instruments, however, the celestial body is viewed directly and the image of the bubble is made to coincide with the body.

## DESCRIPTION OF BUBBLE HORIZON

**Forming the Bubble**—The bubble is formed beneath a concave lens, the plane of which is horizontal when the instrument is held vertically upright. Then, by means of prisms, the



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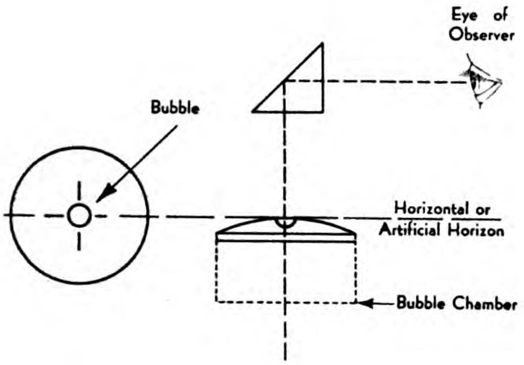


**FIG. 105—BUBBLE'S INDICATION OF HORIZONTAL**

eye views the bubble vertically through the bubble chamber (Figure 105).

The various type octants employ artificial bubble horizons which are either permanent, semi-permanent, or "make and break" type.

**Permanent**—The bubble is formed at the factory by adjusting the amount of liquid in the chamber. In this type of bubble horizon, temperature changes sometimes cause the bubble to disappear entirely. The bubble chamber, however, is usually a separate, interchangeable unit, and several chambers containing bubbles of various sizes are available in the carrying case.

**Semi-Permanent** — The bubble already is formed and may be enlarged or reduced as desired by a special adjusting mechanism.

**"Make and Break" Type of Bubble**—This is a very good type of bubble once the navigator has become accustomed to using it. The bubble must be formed before each observation, however, and as the size of the bubble tends to vary with temperature it is sometimes necessary to make adjustments during observation of a celestial body. The author used this type of bubble for over two years with excellent results, but a beginner should not attempt to form the bubble or change its size until he understands thoroughly the various characteristics of the bubble cell.

In this type of bubble arrangement there are two chambers completely filled with liquid: a bubble chamber with glass top and bottom which forms part of the optical system of the telescope, and a diaphragm chamber with a small connecting passageway between the two. A control nut pulls the diaphragm out to form the bubble (see Figure 103).

Frequently there is formed in the diaphragm chamber a bubble too large to pass through the connecting passage into the bubble chamber, independent of the fact that there may or may not be another bubble visible in the bubble chamber. When this occurs, rotation of the control nut to form a bubble only increases the size of the bubble present in the diaphragm chamber, making it impossible for it to pass into the bubble chamber.

The presence of the bubble in the diaphragm chamber can be detected by the reaction of the diaphragm to rotation of the control nut. Thus when a bubble is visible in the bubble chamber, rotation of the control nut will alter the size of the visible bubble more slowly than when no bubble is present in the diaphragm chamber. This is due to the fact that change in pressure acts to alter the size of the bubble in the diaphragm chamber as well.

It is also noticeable that when there is no bubble visible in the bubble chamber, resistance felt when rotating the nut to form a bubble builds up gradually, as contrasted with a sudden building up of the resistance when another bubble is present.

Therefore, to properly form a bubble, the first step should always be (even though the bubble is visible) to hold the octant with the *control nut downward* at an angle of about 45° from the vertical and rotate the nut so as to put pressure on the liquid. If a bubble exists in the diaphragm chamber this will reduce its size, permitting it to pass into the bubble chamber. Sometimes when the bubble exists in the diaphragm chamber, it may be necessary to hold the instrument at this angle for a minute or two, shaking the octant from time to time until the bubble becomes small enough to pass into the bubble chamber.

Next, if no bubble has appeared, with the octant still in the inclined position *rotate the control nut just far enough to overcome the resistance* of the diaphragm, which should build up suddenly. When the bubble forms it will usually be accompanied by a sharp click, which can be felt on the control nut as the resisting force



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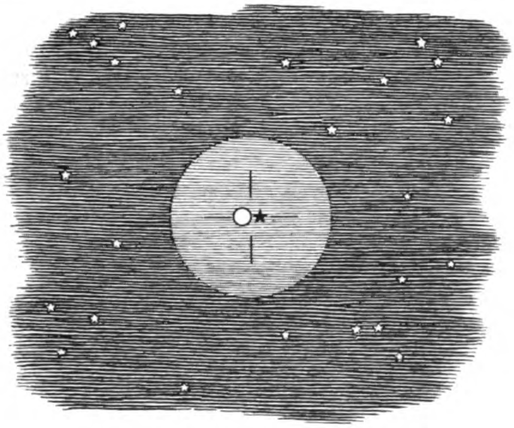

FIG. 106—OCTANT "FIELD"

is released. Then, immediately rotate the nut in the opposite direction in order to apply some pressure on the liquid. This will prevent the formation of too large a bubble and also reduce the size of any bubbles present in the diaphragm chamber so they can pass into the bubble chamber. Rotation of the control nut back and forth several times, each time releasing the suction on the liquid, will speed up the removal of all bubbles from the piston chamber. The control nut now may be set to produce a bubble of the proper size.

**Collimation and Field**—The bubble octant is so designed that when the image of the celestial body is caused to coincide, or match, with the center of the bubble, the angle as read on the octant will be the observed altitude of the celestial body. "Collimation" is the name given the condition of bubble and celestial body in coincidence.

The "field" of the octant is the small section of the celestial sphere which is visible in the octant's eyepiece (Figure 106). The larger the field of view, the easier it is for the navigator to bring the image of the correct celestial body and the bubble into collimation.

**Position of Bubble With Relation to Celestial Body**—The optics of the bubble octant are such that collimation need not necessarily take place in the middle of the field, although the center is most desirable.

In Figure 107 the bubble and sun are shown in collimation in various parts of the field.

In No. 1 is shown the best position in the field.

In No. 2, error will be practically zero when collimation occurs anywhere on a vertical line passing through the center of the field.

In No. 3, large errors (about 5′) will occur if collimation is effected anywhere in the field except on the vertical passing through the center. This appears contrary to reason, but actually, when collimation occurs along the vertical passing through the center of the field, the octant is aligned with the *vertical circle* passing through the celestial body. Collimation anywhere else indicates that the octant is being held in such a way as to increase the angle of altitude (Figure 108).

## OCTANT ERRORS

**Description**—Aircraft octants are subject, basically, to two types of error: *Instrument error and bubble acceleration error.* Instrument error may be classed as a fixed calibration error, as it is caused by improper alignment of the measuring mechanism. It is fixed because it is an error which may be eliminated or, if not eliminated, accurately determined and recorded as *Instrument Correction* (I. C.) to be applied to each observation. Bubble acceleration error, however, is an observation error which is not fixed but varies with each observation taken.

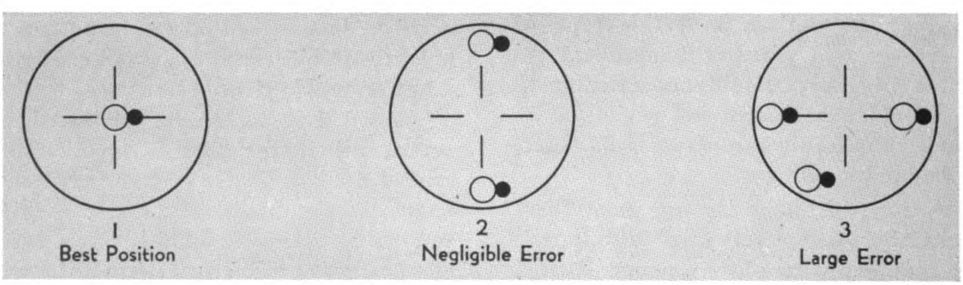


FIG. 107—COLLIMATION



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The bubble is freely suspended in liquid in order that the gravitational attraction of the earth will cause it to indicate the horizontal. But, unfortunately, the bubble also responds to the acceleration of the aircraft which frequently causes it to indicate a false horizon.

**Instrument Error**—Instrument error may be due to *index* or *bubble error*, or to a combination of both.

1. **Index Error**—Index error results when movements of the index prism or mirror are improperly recorded on the graduated scale. When the index prism, which actuates the counter, is in proper alignment (i.e., parallel to the horizon prism), the counter should read zero. If it does not, there is index error present.

To check for index error, a celestial body or distant object on the earth, such as the sea horizon, is viewed directly through the horizon prism. The reflected image of this object, as seen in the index prism, is brought into coincidence with the object itself. This will cause the two prisms to be placed in true alignment, and the counter should read zero. If it does not, the counter or index prism may be adjusted. However, in most octants this requires **extremely** accurate handling. Most navigators prefer to record the amount of error, and to apply this correction to each observation.

For example, if the counter read 5′ off the scale (less than zero), all altitudes as read on the octant would underread 5′. Therefore a 5′ correction should be *added* to all observations. On the other hand, if the counter read 5′ on the scale (greater than zero), a 5′ correction should be *subtracted* from all observations.

2. **Bubble Error**—Instrument bubble error results when the bubble chamber is out of line with the optics of the instrument, which causes the bubble to indicate a false horizontal when the acceleration of gravity alone is influencing it.

Bubble error may be determined by mounting the octant on a steady surface, selecting some distant point on the same level as the sextant (either a point determined by a surveyor's level or the sea horizon) and causing the reflected image of such a point to coincide with the bubble's center. Counter should then indicate zero. If it does not, the error may be eliminated by adjusting the zero reference line of the scale, by realigning the bubble chamber, or by adjusting the mirrors.

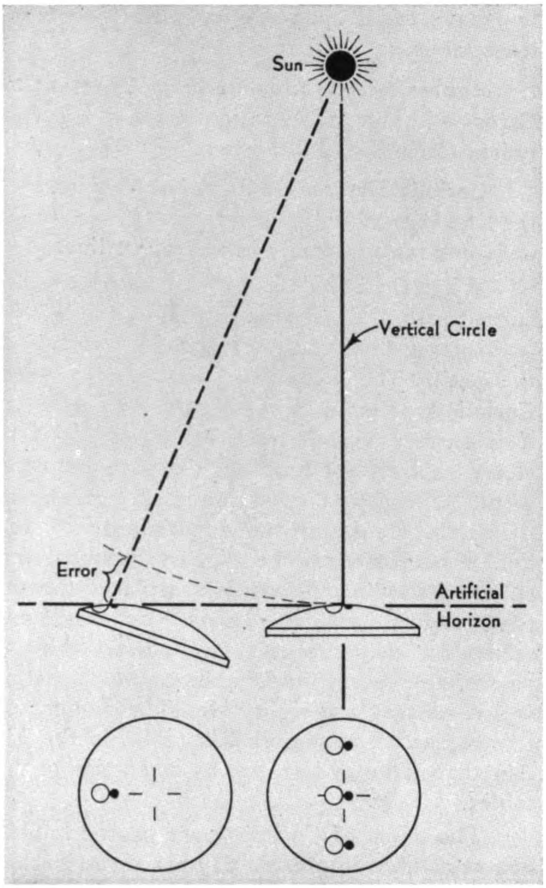


FIG. 108—DEVIATION FROM VERTICAL CAUSES ERROR

**Note:** If the sea horizon is used, the dip correction must be taken into consideration.

Since the primary purpose of the octant is to measure the altitudes of celestial bodies from the bubble horizon, most navigators prefer to know the *total* instrument error. Total instrument error can best be determined by plotting a pre-computed curve showing the exact altitude of a celestial body for a period of several hours. The octant is then placed on a rigid support and the altitude of the body measured about every 15 minutes. The amount by which the octant reading differs from the true altitude as shown on the curve is, therefore, the amount of instrument error which, if not eliminated by adjusting the zero reference line of the scale,



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will have to be applied to all future observations taken.

**Bubble Acceleration Error or Observation Error** — Bubble acceleration error is of two types: Coriolis and Transient.

**Coriolis Error** — A level bubble indicates the true vertical only when the bubble is at rest or is moving uniformly in a straight line.

When the bubble is moving uniformly in a curved path, the zenith indicated by the bubble is displaced toward the center of curvature of the path. The physicist Coriolis, for whom Coriolis type error is named, proved that even if a surface vessel (and hence an aircraft) steered a constant heading, the path followed would be slightly curved due to the rotation of the earth. Hence, altitudes measured with the bubble octant would be slightly in error, and the resultant lines of position displaced toward the center of curvature. In the Northern hemisphere the curvature is always toward the left side of the course, and in the Southern hemisphere toward the right side. The amount of this correction is compiled in tables in the Air Almanac and may be noted by inspection of the tables.

The effect of Coriolis error on the bubble octant as used in present day aerial navigation is, however, almost negligible. And since practical air navigation is not yet an exact science, the navigator need not be overly concerned with finding the exact Coriolis correction to apply to each line of position. With the development of faster long-range aircraft, and especially when flying in higher latitudes, it probably will prove necessary to apply Coriolis correction.

**Transient Error**—Transient error is error caused by accelerations or sluggish movement of the bubble due to slipping, skidding, varying airspeed and turning of the aircraft. This error is always present when observations are taken in the air, and is the principal reason why determining the true altitude of a celestial body is the most difficult and least accurate step in celestial navigation.

Transient errors in a single observation are frequently as great as 1° or 2° (60 to 120 miles). In order to reduce these errors to a minimum several precautions may be taken:

First, observation should be taken as nearly as possible from the center of gravity of the aircraft.

Second, the bubble should be adjusted to correct size, which is about twice the size of the sun as seen through the eyepiece. If the bubble is too large it will bounce around rapidly from one part of the field to another, making it very difficult to bring the body and bubble into coincidence in the center of the field. If the bubble is too small it will tend to lag, thus indicating a false horizon.

Third, averaging a number of readings taken over a period of time will give the mean of all possible horizontals the bubble indicated during the course of observation. Hence accuracy of the mean altitude increases in direct proportion to the time and number of sights taken; however, much depends upon the condition of the air and the skill of the navigator. With skill, 10 sights taken over a period of two minutes will give very good results.

## HANDLING THE OCTANT

The aircraft octant is of rugged construction for aircraft use, but it should be remembered that it is a delicate instrument and should be handled with extreme care at all times. Intelligent use of most aircraft octants requires extensive practice (at least 50 observations) before a navigator begins to acquire a confident "feel" of the instrument. With practice, and by exercising all care humanly possible in taking an observation, he will consistently obtain good results.

The navigator should know all the parts of his octant, how they work and why, and before beginning an observation be sure they are all functioning properly. Prisms, mirrors, and eyepiece should be kept clean, and the eyepiece focused correctly. Also, the bubble should be adjusted to correct size. If a night sight is to be taken, the sun shades should be clear of the field of view, the batteries adjusted, and the light in perfect working order. The procedure in taking a sight is substantially as follows:

1. Scan the sky and select the stars to be "shot," choosing them so that the resulting position lines will intersect to provide a clear idea of the ship's position.



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**FIG. 109—AIRCRAFT OCTANT IN USE**

**Note:** Selection of a star for purposes of a fix is important. Will it provide a speed line, course line, or check on other lines? Stars which are dim and hard to see, or stars which are obscured by occasional clouds should be shot first, as this will lessen the time between sights. If the sky is clear it is usually best to shoot the course line star first, then check line star, and the speed line star last.

2. Set the approximate altitude of the star on the octant and then make sure you have the right star in the field of view. Check by moving the field of view slightly to see relation of the star to other stars nearby, or check it by lining it up with the ribs in cockpit which hold the glass panes.

3. Select a position in the plane as near the center of gravity as possible from which the celestial bodies will be easily visible.

4. When ready to shoot, notify the captain, so that he may concentrate on holding the plane on as constant and steady a heading as possible.

5. Start shooting. It is best always to take three different star observations whenever possible. Establish a system and always shoot the same way thereafter in order to gain proficiency. Speed is desirable, but not essential. Never compromise accuracy for speed.

The author's system when using a non-averaging instrument, is as follows:

1. With the approximate altitude set, check the time on the chronometer, which is fastened to the octant.

2. Note the even minute, and when the second hand comes around to it, start shooting.

3. Record the observed altitude once every 15 seconds for two minutes and 15 seconds, each time causing the body to move out of coincidence a distance of several bubble diameters (up or down) and then realigning them. Thus ten sights are obtained, the mean altitude being found by adding up the minutes of altitude and then moving the decimal point over one digit. The mean time is obtained by adding one minute, seven seconds to the starting time.

*Example:*

| **Arcturus** | **Altitude** |
|---|---|
| Time Start = 23:46:00 | 47°30′ |
| Add = 01:07 | 25′ |
| Mean Time = 23:47:07 | 25′ |
| | 15′ |
| | 30′ |
| | 25′ |
| | 10′ |
| | 25′ |
| | 25′ |
| | 35′ |
| | 24.5′ |
| Index Error = | +5′ |
| | $H_s$ = 47°29.5′ |
| | Ref. —1′ |
| | $H_o$ = 47°28.5′ |



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When using an averaging octant the procedure is somewhat simpler. Note the time and start shooting on the even minute. While keeping the body and bubble in continuous coincidence, move the recording lever at regular intervals of two or three seconds for a period of two minutes. At the end of this time the average altitude is found by adjusting the index control so that the middle point of the marks left by the recorder is opposite the recorder point (usually a pencil lead) or other reference mark. The altitude is then read directly from the scale. The average time will be the starting time plus one minute.

In addition to the aforementioned methods of averaging sights there are devices which provide sight averages automatically. Several makes of octants feature various types of automatic averagers. One such averager is the so-called "cone" type, on which a constantly moving stylus records the altitude of the celestial body on a small sleeve of graph paper which slips over a cone-shaped holder, mounted on the altitude control knob. While the observer keeps the body and bubble in collimation over a two-minute period, the stylus records a curve on the graph paper. Examination of this curve provides the body's average altitude.

Another automatic averager records on a speedometer type dial the instantaneous average altitude of a celestial body for a period of two minutes. At the end of this time a shutter closes, indicating termination of the two-minute period. The final reading on the averager represents the average altitude of the sight for the period. This is usually a very accurate average as it actually represents an average of 120 sights (one per second for two minutes).



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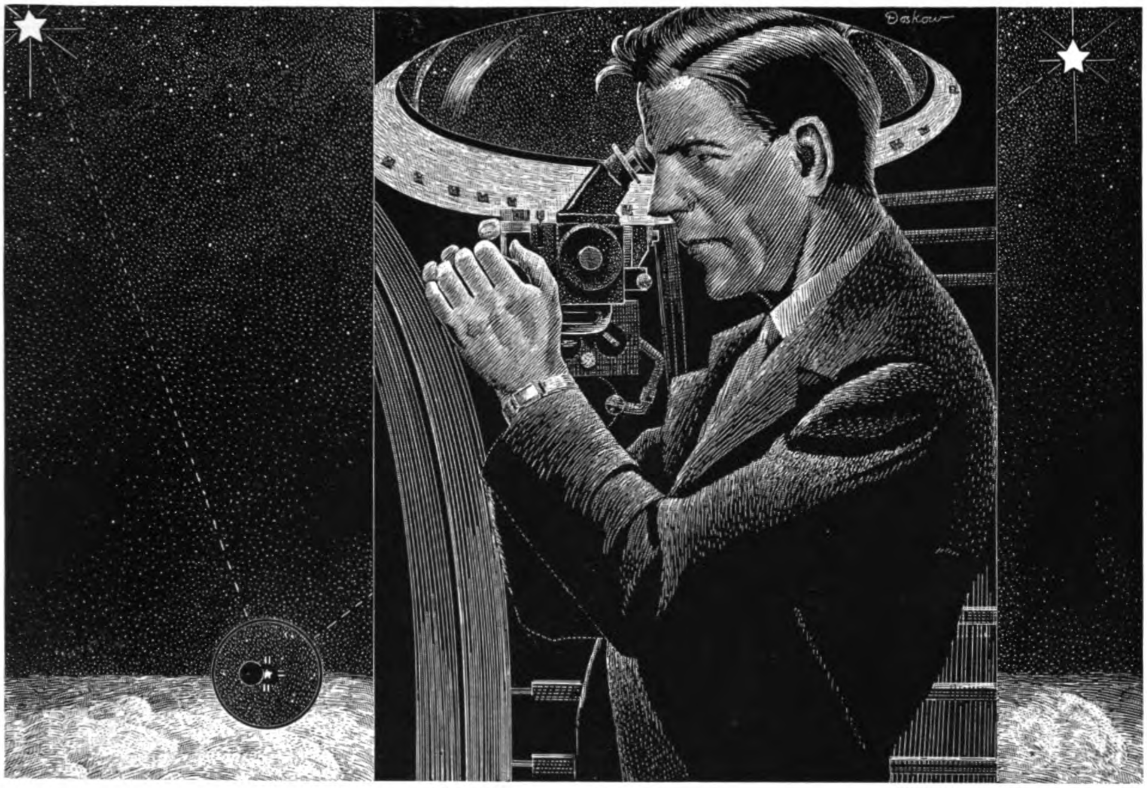

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# POSITION LINES

As was stated in the preceding chapter, the development of the sextant marked an important milestone in the science of navigation. Though the instrument made it possible to measure the altitude of a celestial body more accurately, mariners still were able to determine only their approximate position, and then only after performing much tedious computation.

Like many a mariner who had sailed before him, Capt. Thomas H. Sumner, an American shipmaster, was acutely aware of the fact that the altitude of heavenly bodies could help men find their positions on the surface of the earth. In December, 1837, Capt. Sumner finally made a discovery which launched the science of navigation into its most important era. This discovery is known as the "line of position," though in honor of its discoverer, it is often referred to as the Sumner line. It has been termed by one authority "the most important principle in modern navigation."

Though Sumner's contribution was a vital one, it remained for a French naval officer, Marcq Saint-Hilaire, to combine the solution of the astronomical triangle with his DR position and so obtain a line of position faster and more directly. His contribution is generally considered the cornerstone of celestial navigation as it is practiced today.



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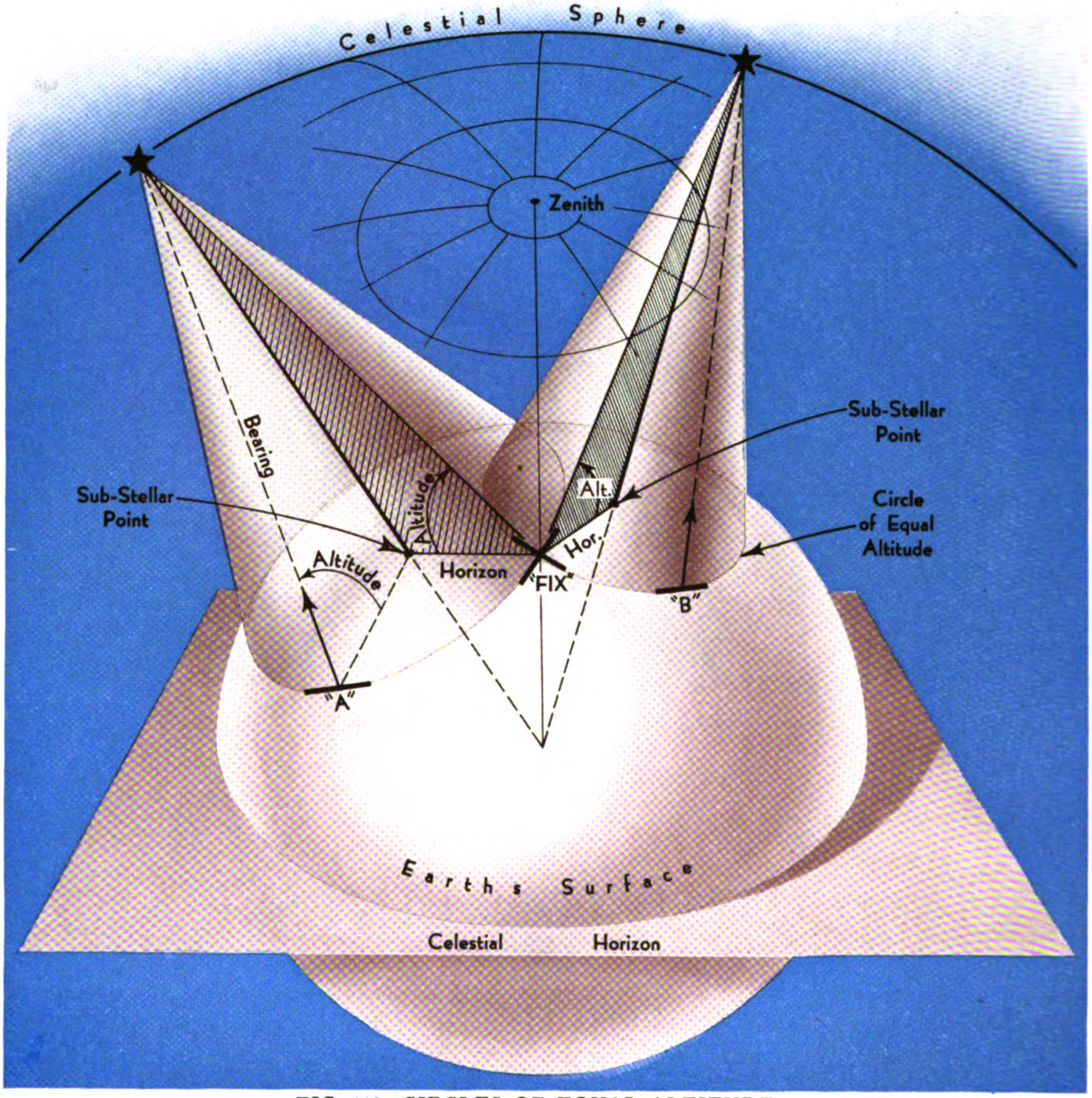


FIG. 110—CIRCLES OF EQUAL ALTITUDE

**THEORY**

**Circle of Equal Altitude**—A circle of equal altitude (Figure 110) is a small circle on the earth's surface, from any point of which (at the same instant of time) the altitude of a celestial body would be the same.

**A Line of Position** is a small segment of a circle of equal altitude. Being a portion of a circle, it is actually a curved line. However, since the circle is usually very large, for purposes of navigation this segment is considered a straight line perpendicular to the azimuth, (bearing of the celestial body), as illustrated in Figure 110 at positions "A," "B," and at "Fix."

**Position Line Fix**—As will be noted in Figure 110, the true altitude of a celestial body determines the radius of the circle of equal altitude, or the observer's position with relation to the *geographical position*. It also will be noted that the observer could be located anywhere on this circle, such as at position "A" or



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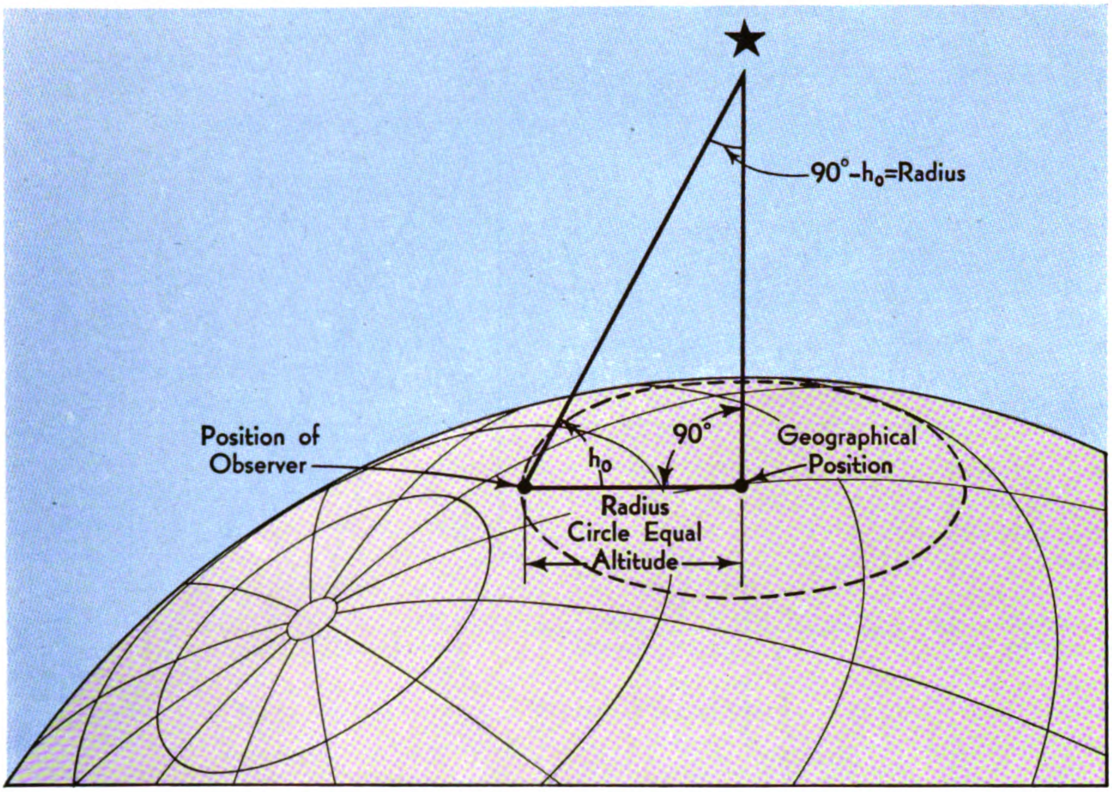


FIG. 111—RADIUS CIRCLE OF EQUAL ALTITUDE $= 90° - h_o$

at the fix. If the altitudes of two or more celestial bodies are measured, since the observer's position is somewhere on each circle of equal altitude, he can only be located at one of the intersections of these circles. And though these circles will cross at two points, only one of these intersections may logically be the navigator's position, the other usually being so remote that it can be disregarded. The point of intersection at which the observer is located, when plotted on the chart, is called a "fix," or known position of the aircraft for the time of sight.

**The Geographical Position** (G.P.) is that point on the earth's surface directly beneath a celestial body and is, therefore, the center of the circle of equal altitude (Figure 110). It is sometimes called the sub-solar, sub-lunar or sub-stellar position to indicate sun, moon or star as the celestial body used.

Since declination is celestial latitude and Greenwich hour angle is celestial longitude (both contained in the Air Almanac for any instant of time), the geographical position of a celestial body may be located exactly on the earth's surface, using declination as latitude and GHA as longitude.

**Observer's Relation to Geographical Position** — Since the geographical position is directly beneath the celestial body, a right triangle is formed between the observer's position, the geographical position, and the celestial body itself. And since the three angles of a triangle total 180°, the radius of a circle of equal altitude is equal to 90° minus the altitude of the celestial body (Figure 111).

On the earth's surface, one degree (60 minutes) of arc of a great circle is equal to 60 nautical miles. Therefore, the angle at a celestial body (converted into minutes) equals the radius of the circle of equal altitude in nautical miles, or the *distance of the observer from the*



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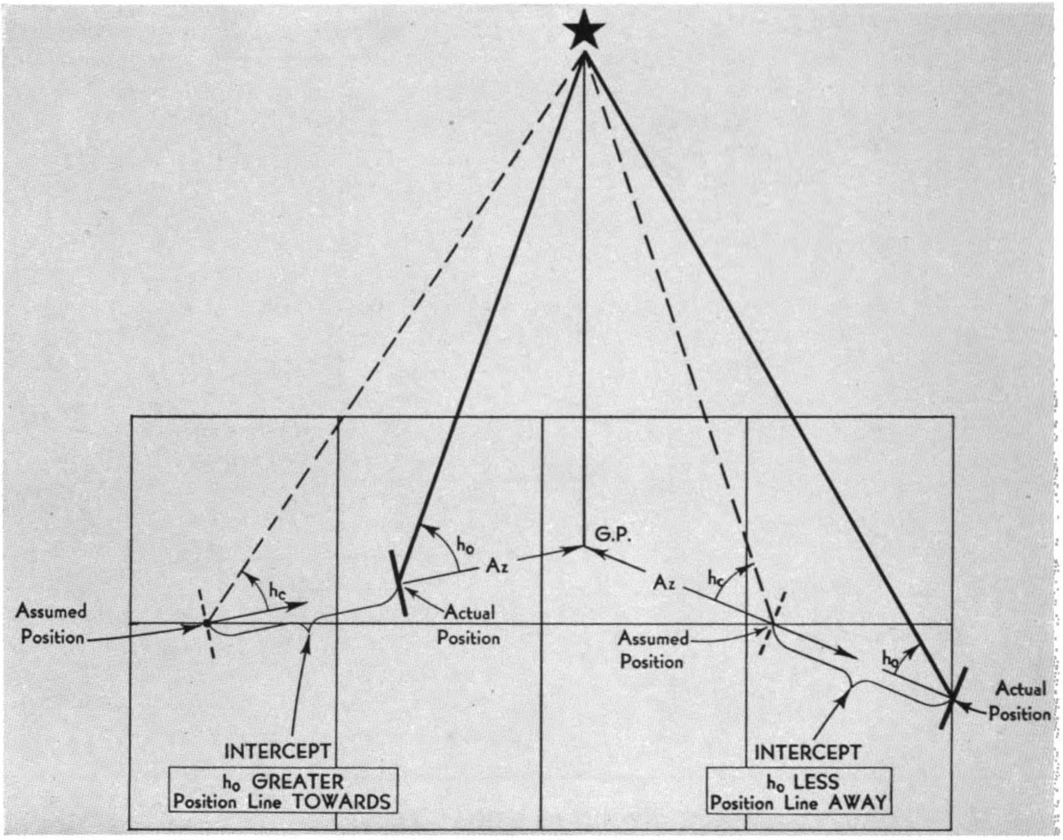


FIG. 112—ALTITUDE INTERCEPT

*geographical position*. The observer's position is determined then as somewhere on the small segment of the circle of equal altitude perpendicular to the azimuth line, such as at "A," "Fix," and "B" (Figure 110).

For a celestial body near the zenith, the circle of equal altitude would be small and could be plotted directly on the chart. However, for each minute the altitude *decreases* the observer's distance (radius of circle of equal altitude) *increases* one nautical mile. As a result, for the majority of sights the circle of equal altitude is too great for convenient plotting. Moreover, the azimuth cannot be measured closely enough for accurate navigation.

For these reasons the astronomical triangle is solved, and the observer's position relative to the celestial body's geographical position is computed by reference to tables of pre-computed altitude and azimuth. These tables give the navigator the true altitude and azimuth of any celestial body, at any instant, for any given position on the earth's surface. Tables of this type have been printed in many different forms, each striving to minimize the amount of work involved. However, results obtained by any one of several accepted methods will be similar.

**General Procedure** of computing a line of position is as follows:

a. The navigator measures the altitude of a celestial body with his octant, and at the same instant notes the GCT. The observed altitude ($H_S$), when corrected for sextant and altitude errors, becomes the *true altitude* ($H_O$) of the celestial body from the aircraft's actual position at the exact time of observation.

b. The GCT, by reference to the Air Almanac, gives the *GHA* and *declination* of the body, thus locating its geographical position for that instant of time.

c. Next, by reference to a table of pre-computed altitude and azimuth, the navigator determines the true altitude and azimuth, at the time of



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sight, for his *assumed* or *dead reckoning* position, which is estimated as near to the actual position of the aircraft as possible.

d. Comparing the two altitudes (Figure 112), if both the observed true altitude ($H_O$) and the computed altitude ($H_C$) are equal, the aircraft is somewhere on the line of position passing through the assumed or dead reckoning position. For each minute that true altitude ($H_O$) is *greater* than computed altitude ($H_C$), the line of position of the aircraft is one nautical mile *toward* the geographical position, measured from the assumed position. Conversely, for each minute that true altitude ($H_O$) is *less* than computed altitude ($H_C$), the line of position of the aircraft is one nautical mile *away* from the geographical position, measured from the assumed position.

This distance of the aircraft's actual line of position *toward* or *away* from the geographical position is called the *altitude intercept* ("a").

**H.O. 214**—"H.O. 214" is the designation for a group of books published by the U. S. Hydrographic Office (H.O.). These contain tabulated solutions of the astronomical triangle, so arranged as to yield to the navigator his computed altitude and azimuth by inspection. The books are rather large in size, and because each book covers only ten degrees of latitude, the navigator is required to take several volumes on an average flight. However, these tables are widely used because they require little computation, and thus reduce the chance of mathematical error. This is very important to the long range aerial navigator, because, after flying several hours at high altitudes, he is apt to make mistakes due to fatigue.

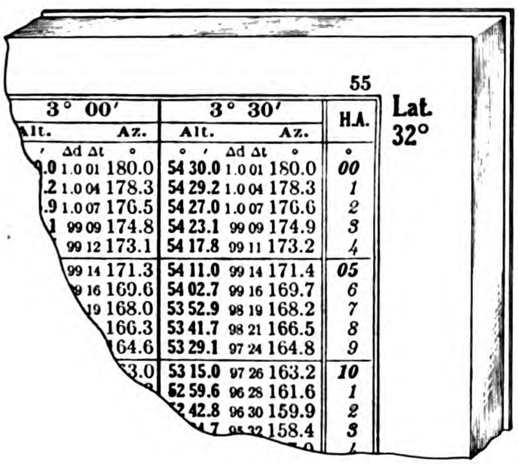


FIG. 113

**Note:** A newer method, known as H.O. 218, and developed by the British, also is very popular. The tables are similar to H.O. 214; however, they are a little easier to use because of the fact that the declinations of 22 stars have been included, eliminating the necessity of interpolation of declination for these stars. Otherwise, H.O. 218 is essentially the same as H.O. 214 for solutions of any celestial body whose declination is from 0° to 28°.

**Use of Tables**—The H.O. 214 tables may be used to find the true altitude and azimuth of a body for an aircraft's estimated *dead reckoning position;* however, in order to reduce the amount of interpolation required, they are generally used to find the altitude and azimuth for an *assumed position.* The assumed position is found by taking the nearest whole degree of dead reckoning latitude and the value of dead reckoning longitude which will yield a whole degree of local hour angle.

**Arguments to Enter the Tables**—The arguments necessary to enter the tables are:

1. Nearest whole degree of latitude.
2. Nearest whole or half degree of declination.
3. Nearest whole degree of local hour angle.

The values obtained are *altitude, azimuth,* and $\Delta d$ ("delta d"). The information is arranged in the following order: Altitude—$\Delta$d—$\Delta$t—azimuth (see Figure 113).

$\Delta$t is disregarded, as it represents the change in altitude for a change of one minute of arc of hour angle, whereas in using assumed position the hour angle employed is a whole degree. $\Delta$t is used in obtaining altitude when working from a DR rather than an assumed position.

$\Delta$d, however, represents the change in altitude for a change of one minute of arc of declination, and since the exact declination of a celestial body usually will differ from the tabulated declination, the $\Delta$d value is multiplied by the number of minutes of declination difference to obtain the correction to altitude. (This correction may be had by inspection from



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the multiplication table arranged on the inside back cover of the volume or, with a little practice, it may be easily computed).

The application of this correction is determined by examination of the tabulated altitudes. If the values of altitude are *increasing* as the tabulated value used approaches the exact declination, the correction is *added* (indicated by a plus sign); if the values of altitude are *decreasing,* the correction should be *subtracted* (indicated by a minus sign). The altitude thus obtained is the *computed* altitude ($H_C$) for the *assumed position.*

**Procedure** to obtain line of position by H.O. 214 is as follows:

a. Find the true altitude ($H_O$) by correcting the observed altitude ($H_S$) for octant errors (I.C.) and altitude errors.

b. Find Greenwich hour angle and declination for the instant of Greenwich civil time of sight from the Air Almanac.

c. Assume value of longitude nearest to dead reckoning position that will yield a whole degree of local hour angle. Note direction of LHA, East or West, as this determines whether the body is rising or setting, and is used to name the azimuth.

LHA has been described as the angular distance of the celestial body from the observer. It is easily determined by simple arithmetic and the hour angle diagram, or by use of the following formula:

LHA = GHA — West Longitude
(Add 360° to GHA if necessary)
LHA = GHA + East Longitude

**Note:** The above formulas will result in values of LHA to 360°. However, in using H.O. 214 (or any other method of solving the astronomical triangle), LHA is measured only to 180° and named East or West with reference to the observer. Thus, if the value obtained by use of the formulas is less than 180°, it is named West; if, on the other hand, the value obtained is greater than 180°, it must be subtracted from 360° and then named East.

Note also that in West longitude LHA is always found by subtraction. Hence, the minutes of assumed longitude must equal the minutes of GHA in order for the LHA to come out in whole degrees.

In East longitude, the LHA is always found by addition, hence the minutes of assumed longitude when added to the minutes of GHA must total 60 minutes or one degree for the LHA to come out in whole degrees.

The following examples show how LHA is obtained.

*Example* No. 1 (Figure 114) →

DR Position = Latitude 30°12′ North
Longitude 117°23′ West

| | | |
|---|---|---|
| GHA = | 93°19′ | |
| Assumed Long. = | 117°19′ | West |
| LHA = | 24° | East |
| —or— | | |
| GHA = | 93°19′ | |
| | +360° | |
| | 453°19′ | |
| Assumed Long. = | 117°19′ | West |
| LHA = | 336°00′ | West |
| from | 360° | |
| LHA = | 24° | East |

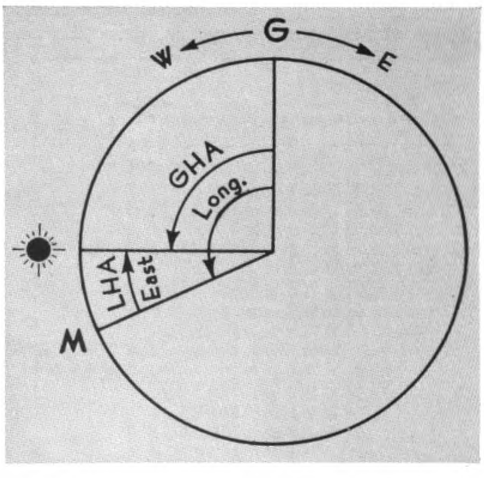


FIG. 114—LHA = GHA — WEST LONGITUDE



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*Example* No. 2 (Figure 115)

| | | |
|---|---|---|
| DR Position = | Latitude 33°20′ North | |
| | Longitude 160°15′ East | |
| GHA = | 269°28′ | |
| Assumed Long. = | 160°32′ | East |
| | 430°00′ | |
| | —360° | |
| LHA = | 70° | West |

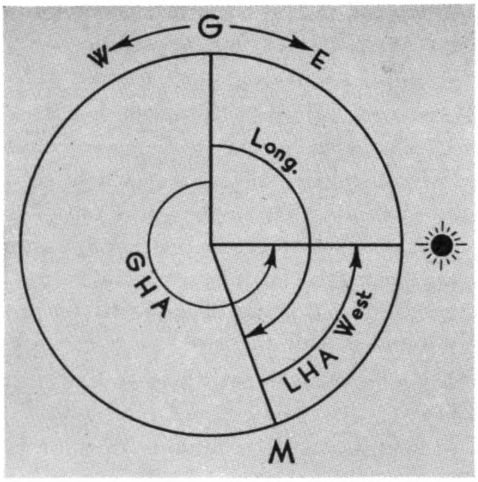


FIG. 115—LHA = GHA + EAST LONGITUDE

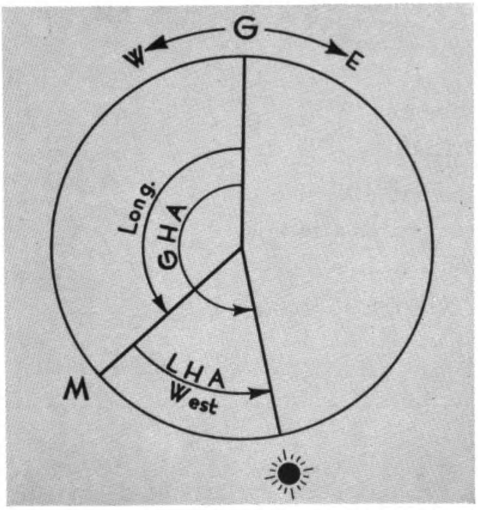


FIG. 116—LHA = GHA — WEST LONGITUDE

*Example* No. 3 (Figure 116)

| | | |
|---|---|---|
| DR Position = | Latitude 34°36′ North | |
| | Longitude 132°00′ West | |
| GHA = | 190°51′ | |
| Assumed Long. = | 131°51′ | West |
| LHA = | 59° | West |

*Example* No. 4 (Figure 117)

| | | |
|---|---|---|
| DR Position = | Latitude 31°45′ North | |
| | Longitude 120°50′ East | |
| GHA = | 158°47′ | |
| Assumed Long. = | 121°13′ | East |
| | 280°00′ | |
| from | 360° | |
| LHA = | 80° | East |

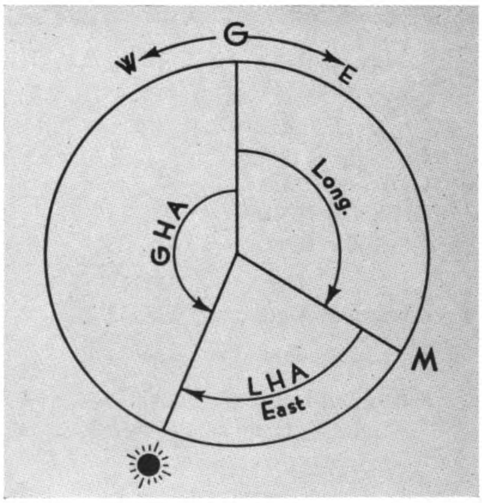


FIG. 117—LHA = GHA + EAST LONGITUDE



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d. **To continue procedure,** assume latitude, nearest whole degree to DR position.

e. Enter proper volume of H.O. 214 and find assumed latitude. Note whether declination is *same name* as latitude or *contrary* to latitude. Find column of nearest whole or half degree of declination as shown at top of page (according to whether declination is same or contrary name to latitude), obtain values for altitude, $\Delta$d, and azimuth opposite the proper LHA found at side of page.

f. Name azimuth according to latitude and LHA.

g. Multiply $\Delta$d by number of minutes of declination difference and apply correction to tabulated altitude in order to obtain computed altitude ($H_c$) for assumed position.

h. Compare $H_c$ with $H_o$ and mark altitude intercept *toward* or *away* depending on whether $H_o$ is greater or less than $H_c$.

**Caution**—The most important factor in computing lines of position is accuracy. Therefore:

1. Write all work legibly.
2. Establish some such form as used in the following problems, and use it consistently.
3. Underline *assumed longitude, assumed latitude, azimuth,* and *intercept,* as these values are used to plot the line of position.
4. Name latitude and declination to insure use of the correct table.

## SAMPLE PROBLEMS

The following problems illustrate the use of H.O. 214. In each example the navigator measured the altitude of the celestial body with a bubble octant while flying at an altitude of 5000 ft.

*Example* No. 1

May 1, 1943, GCT $18^h10^m12^s$, $H_s$ sun 63°32′, I.C. +1′, DR latitude 30°12′ North, DR longitude 117°23′ West.

**SUN**

GCT $18^h10^m12^s$

| | | |
|---|---|---|
| GHA for $18^h10^m$ | = | 93°14′ |
| + for $00^m12^s$ | = | 03′ |
| GHA | = | 93°17′ |
| **Assumed Long.** | = | 117°17′W |
| LHA | = | 24° E |
| **Assumed Lat.** | = | 30° N |
| Dec. | = | 14°58′N |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 24°N |
| Lat. | 30°N |
| Dec. | 15°N |

| | | |
|---|---|---|
| $H_s$ | = | 63°32′ |
| I. C. | = | +1′ |
| Ref. | = | 0 |
| $H_o$ | = | 63°33′ |
| $H_c$ | = | 63°18.6′ |
| a | = | **14.4′ toward** |
| $\Delta$d | = | .61 (x 2′ = 1.2′) |
| H | = | 63°19.8′ |
| $\Delta$d corr. | | —1.2′ |
| $H_c$ | = | 63°18.6′ |
| Az | = | **N 118.9°E** |



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*Example* No. 2

May 1, 1943, GCT $05^h55^m00^s$, $H_s$ sun 24°30′, I.C. —3′, DR latitude 33°20′ North, DR longitude 160°15′ East.

**SUN**

| | | |
|---|---|---|
| GCT $05^h55^m00^s$ | | |
| GHA for $05^h50^m$ | = | 268°13′ |
| + for $05^m00^s$ | = | 1°15′ |
| GHA | = | 269°28′ |
| **Assumed Long.** | = | 160°32′E |
| | | 430° |
| | | —360° |
| LHA | = | 70° W |
| **Assumed Lat.** | = | 33° N |
| Dec. | = | 14°49′N |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 70°W |
| Lat. | 33°N |
| Dec. | 15°N |

| | | |
|---|---|---|
| $H_s$ | = | 24°30′ |
| I. C. | = | —3′ |
| Ref. | = | —2′ |
| $H_o$ | = | 24°25′ |
| $H_c$ | = | 24°37.2′ |
| a | = | **12.2′ away** |
| $\Delta$d | = | .50 (x 11′ = 5.5′) |
| H | = | 24°42.7′ |
| $\Delta$d corr. | | —5.5′ |
| $H_c$ | = | 24°37.2′ |
| Az | = | **N 87.7°W** |

*Example* No. 3

May 1, 1943, GCT $0^h40^m35^s$, $H_s$ sun 33°40′, I.C. +5′, DR latitude 34°36′ North, DR longitude 132°00′ West.

**SUN**

| | | |
|---|---|---|
| GCT $0^h40^m35^s$ | | |
| GHA for $0^h40^m$ | = | 190°42′ |
| + for $00^m35^s$ | = | 09′ |
| GHA | = | 190°51′ |
| **Assumed Long.** | = | 131°51′W |
| LHA | = | 59° W |
| **Assumed Lat.** | = | 35° N |
| Dec. | = | 14°45′N |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 59°W |
| Lat. | 35°N |
| Dec. | 15°N |

| | | |
|---|---|---|
| $H_s$ | = | 33°40′ |
| I.C. | = | +5′ |
| Ref. | = | —1′ |
| $H_o$ | = | 33°44′ |
| $H_c$ | = | 33°38.5′ |
| a | = | **5.5′ toward** |
| $\Delta$d | = | .54 (x 15′ = 8.1′) |
| H | = | 33°46.6′ |
| $\Delta$d corr. | | —8.1′ |
| $H_c$ | = | 33°38.5′ |
| Az | = | **N 95.1°W** |

*Example* No. 4

May 1, 1943, GCT $22^h32^m10^s$, $H_s$ sun 16°12′, I.C. —6′, DR latitude 31°45′ North, DR longitude 120°50′ East.

**SUN**

| | | |
|---|---|---|
| GCT $22^h32^m10^s$ | | |
| GHA for $22^h32^m$ | = | 158°14′ |
| + for $02^m10^s$ | = | 33′ |
| GHA | = | 158°47′ |
| **Assumed Long.** | = | 121°13′E |
| | | 280°00′ |
| from | | 360° |
| LHA | = | 80° E |
| **Assumed Lat.** | = | 32° N |
| Dec. | = | 15°02′N |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 80°E |
| Lat. | 32°N |
| Dec. | 15°N |

| | | |
|---|---|---|
| $H_s$ | = | 16°12′ |
| I. C. | = | —6′ |
| Ref. | = | —3′ |
| $H_o$ | = | 16°03′ |
| $H_c$ | = | 16°14.4′ |
| a | = | **11.4′ away** |
| $\Delta$d | = | .50 (x 2′ = 1.0′) |
| H | = | 16°13.4′ |
| $\Delta$d corr. | | +1.0′ |
| $H_c$ | = | 16°14.4′ |
| Az | = | **N 82.2°E** |



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*Example* No. 5

May 1, 1943, GCT $21^h13^m10^s$, $H_S$ moon 35°02′, I.C. = 0, DR latitude 30°15′ South, DR longitude 120°30′ West.

**MOON**

GCT $21^h13^m10^s$

| | | |
|---|---|---|
| GHA for $21^h10^m$ | = | 166°20′ |
| + for $3^m10^s$ | = | 46′ |
| GHA | = | 167°06′ |
| **Assumed Long.** | = | 120°06′W |
| LHA | = | 47° W |
| **Assumed Lat.** | = | 30° S |
| Dec. | = | 0°18′N |

Enter H.O. 214
(Contrary name)

| | |
|---|---|
| LHA | 47°W |
| Lat. | 30°S |
| Dec. | 0°N |

| | | |
|---|---|---|
| $H_S$ | = | 35°02′ |
| I. C. | = | 0 |
| Par. | = | +48′ |
| Ref. | = | —1′ |
| $H_O$ | = | 35°49′ |
| $H_C$ | = | 36°00.9′ |
| a | = | **11.9′ away** |
| $\Delta$d | = | .62 (x 18′ = 11.2′) |
| H | = | 36°12.1′ |
| $\Delta$d corr. | | —11.2′ |
| $H_C$ | = | 36°00.9′ |
| Az | = | **S 115.0°W** |

*Example* No. 6

May 1, 1943, GCT $11^h12^m20^s$, $H_S$ star Rigel 14°01′, I. C. —2′, DR latitude 32°20′, South, DR longitude 130°20′ East.

**STAR RIGEL**

GCT $11^h12^m20^s$

| | | |
|---|---|---|
| GHA for $11^h10^m$ | = | 26°01′ |
| + for $2^m20^s$ | = | 35′ |
| SHA Rigel | = | 282°03′ |
| GHA | = | 308°39′ |
| **Assumed Long.** | = | 130°21′E |
| | | 439°00′ |
| | | —360°00′ |
| LHA | = | 79° W |
| **Assumed Lat.** | = | 32° S |
| Dec. | = | 8°16′S |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 79°W |
| Lat. | 32°S |
| Dec. | 8°S |

| | | |
|---|---|---|
| $H_S$ | = | 14°01′ |
| I. C. | = | —2′ |
| Ref. | = | —3′ |
| $H_O$ | = | 13°56′ |
| $H_C$ | = | 13°40.2′ |
| a | = | **15.8′ toward** |
| $\Delta$d | = | .52 (x 16′ = 8.3′) |
| H | = | 13°31.9′ |
| $\Delta$d corr. | | +8.3′ |
| $H_C$ | = | 13°40.2′ |
| Az | = | **S 88.9°W** |

*Example* No. 7

May 1, 1943, GCT $17^h53^m10^s$, $H_S$ Mars 33°50′, I. C. +4′, DR latitude 34°50′ South, DR longitude 160°30′ East.

**MARS**

GCT $17^h53^m10^s$

| | | |
|---|---|---|
| GHA for $17^h50^m$ | = | 143°25′ |
| + for $3^m10^s$ | = | 48′ |
| GHA | = | 144°13′ |
| **Assumed Long.** | = | 160°47′E |
| | | 305°00′ |
| from | | 360° |
| LHA | = | 55° E |
| **Assumed Lat.** | = | 35° S |
| Dec. | = | 8°57′S |

Enter H.O. 214
( Same name )

| | |
|---|---|
| LHA | 55°E |
| Lat. | 35°S |
| Dec. | 9°S |

| | | |
|---|---|---|
| $H_S$ | = | 33°50′ |
| I. C. | = | +4′ |
| Ref. | = | —1′ |
| $H_O$ | = | 33°53′ |
| $H_C$ | = | 33°35.8′ |
| a | = | **17.2′ toward** |
| $\Delta$d | = | .59 (x 3′ = 1.8′) |
| H | = | 33°37.6′ |
| $\Delta$d corr. | | —1.8′ |
| $H_C$ | = | 33°35.8′ |
| Az | = | **S 103.7°E** |



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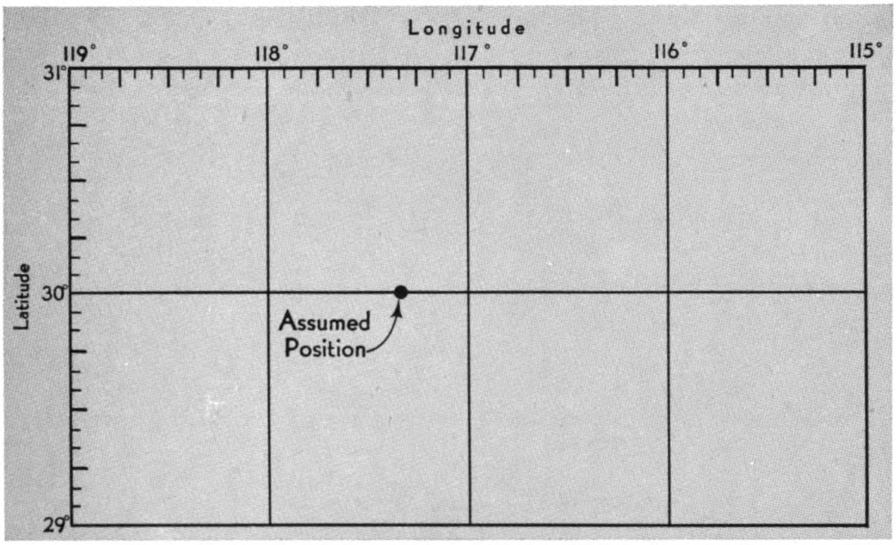


FIG. 118—PLOTTING ASSUMED POSITION

## PLOTTING LINES OF POSITION

**Step One** — *Plotting Assumed Position* — Since the solution of the astronomical triangle by altitude-azimuth tables locates the small segment of the circle of equal altitude (line of position) with relation to an assumed position, the first step in plotting the line of position (L.O.P.) is to locate on the chart the assumed position used in the solution. Thus, if the assumed latitude = 30° North and the assumed longitude = 117°20′ West, this position would be plotted as shown in Figure 118.

**Step Two**—*Plotting Az*—The second step is to plot the azimuth, or bearing of the body, through the assumed position as shown in Figure 119.

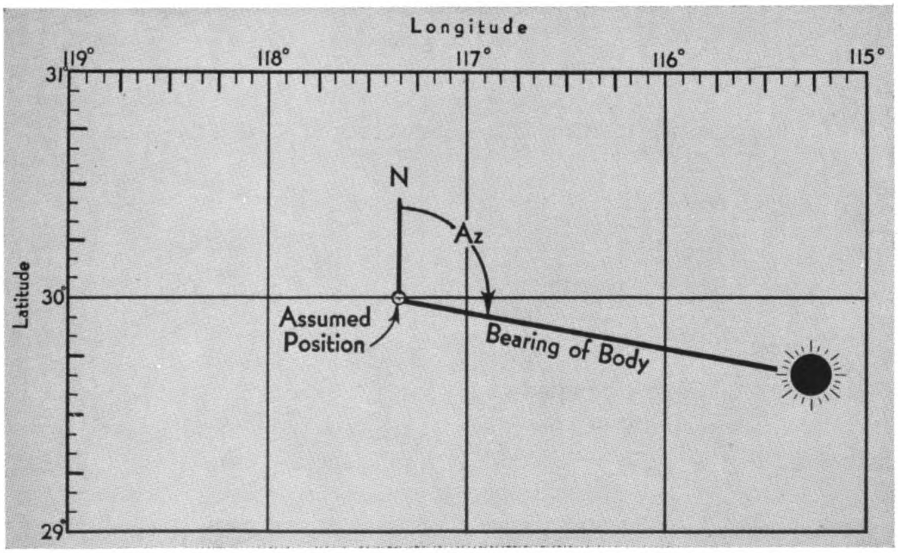


FIG. 119—PLOTTING AZIMUTH THROUGH ASSUMED POSITION



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**Note:** Bearings usually are measured from North (0°) through 360°. Such bearings are called true bearings ($Z_n$). However, precomputed bearings of celestial bodies (as found in H.O. 214), are generally tabulated in terms of azimuth, thus greatly simplifying the tables and eliminating much unnecessary compilation work. When azimuth is so employed, the bearing of a body is measured from the *elevated* pole towards the East or West through 180°. If the observer is in North latitude, the elevated pole is the North pole; if he is in South latitude, the elevated pole is the South pole. Azimuth is measured to the East if the body is rising, or to the West if it is setting.

With this in mind, the navigator should pay particular attention to the azimuth direction, because plotting azimuth incorrectly is the most frequent error made by navigators in plotting a line of position. One of the most practical methods which the author has yet found is to use a Weems plotter, which has an azimuth scale graduated to read from 0° to 180°.

As illustrated in Figure 120, the center of the Weems plotter is placed over the assumed position with the 0° mark pointed toward the elevated pole. Azimuth is then easily measured East or West according to the LHA of the body.

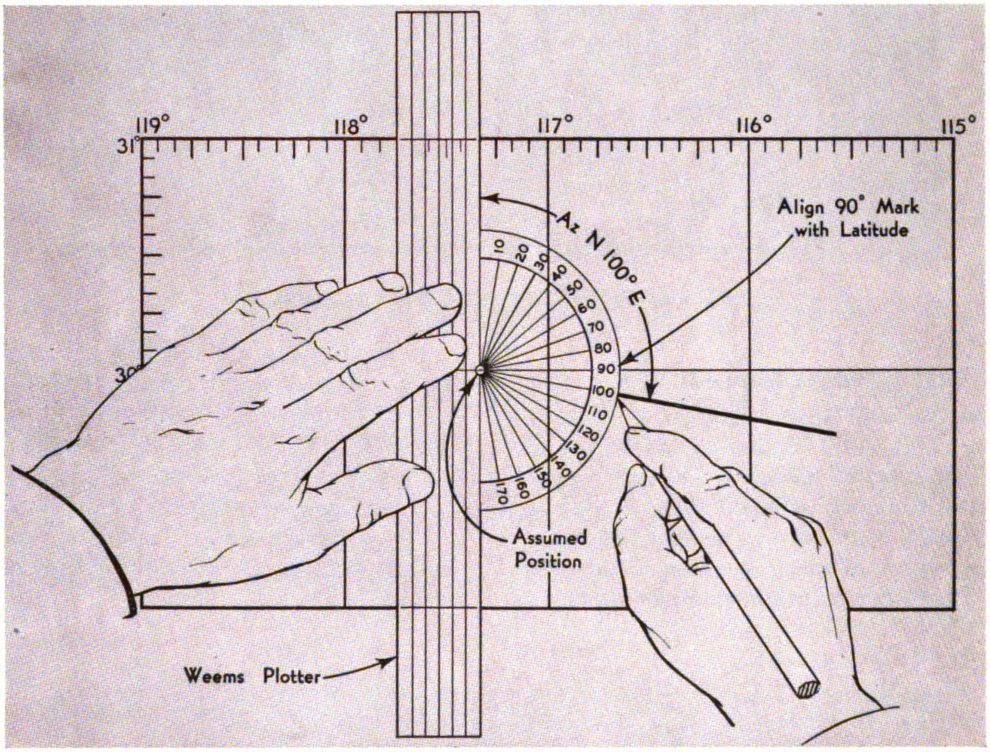


FIG. 120—PLOTTING AZIMUTH WITH WEEMS PLOTTER



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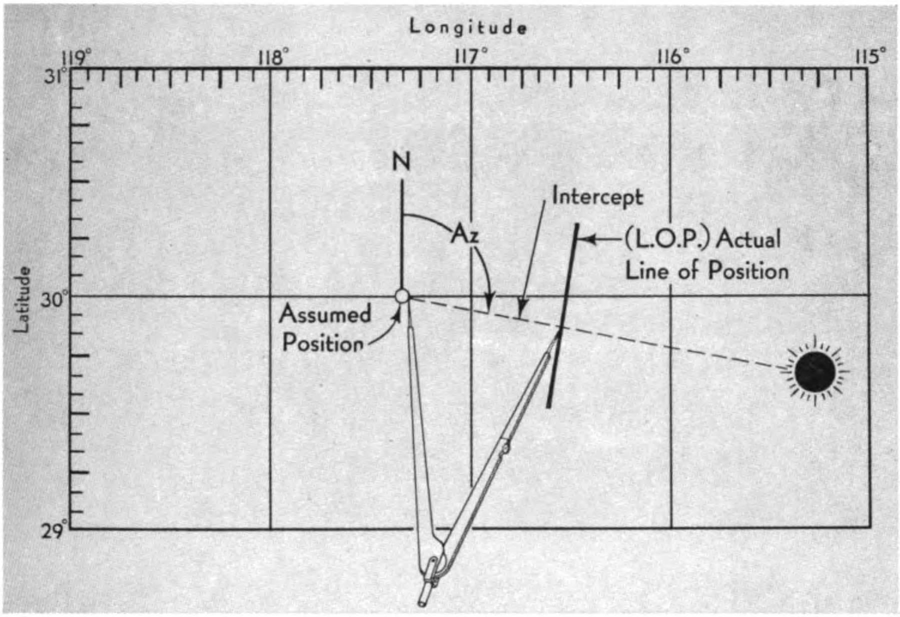


FIG. 121—MEASURING ALTITUDE INTERCEPT AND PLOTTING L.O.P.

**Step Three**—*Plotting Actual Line of Position* (Figure 121)—The third step is to plot the actual line of position. With the dividers set at a distance equal to the altitude intercept, locate a point on the azimuth line a distance from the assumed position equal to altitude

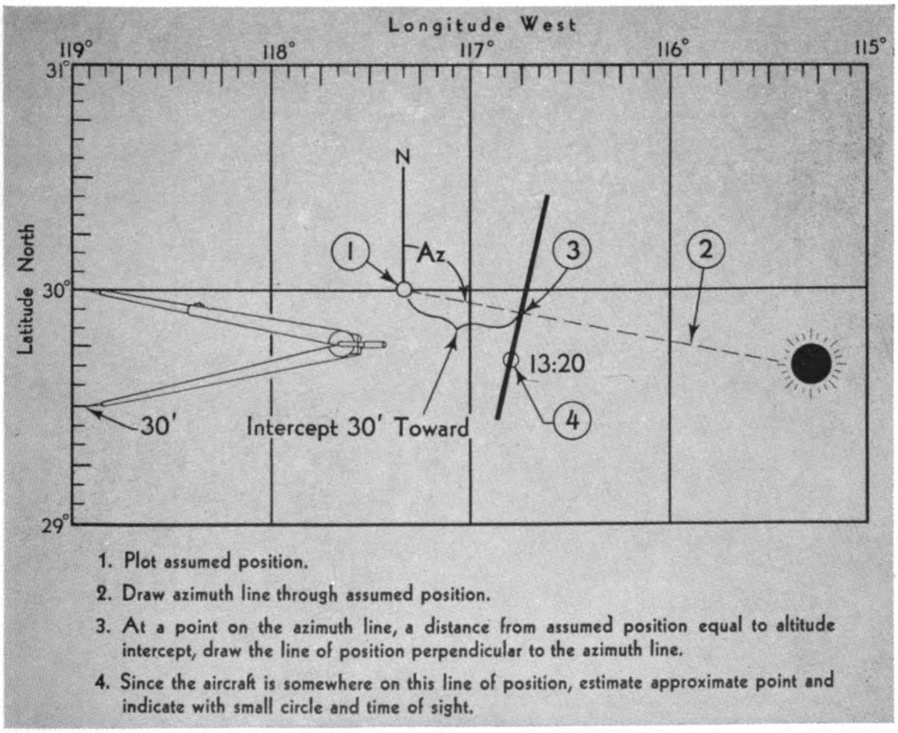


FIG. 122



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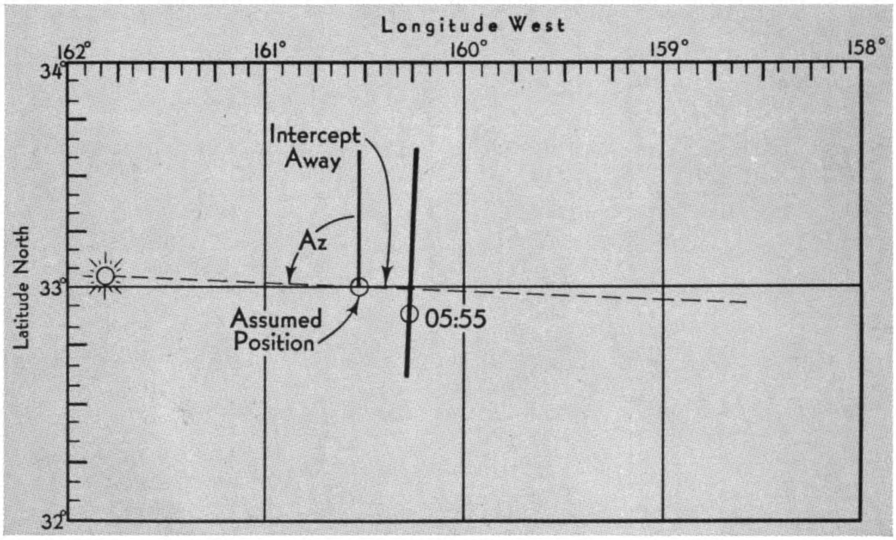


FIG. 123

intercept, and through this point erect the actual line of position perpendicular to the azimuth line.

**Sample Problems**—The following examples show how lines of position are plotted, using H. O. 214.

*Example* No. 1 Sun (Figure 122)
Time of sight..........GCT $13^h20^m$
Assumed position....Latitude 30° North
Longitude 117°20′ West
Azimuth ..................N 100°E
Altitude Intercept....30 miles toward

*Example* No. 2 Sun (Figure 123)
Time of sight..........GCT $05^h55^m$
Assumed position....Latitude 33° North
Longitude 160°32′ West
Azimuth ..................N 87.7°W
Altitude Intercept....13.2 miles away

*Example* No. 3 Moon (Figure 124)
Time of sight..........GCT $21^h13^m10^s$
Assumed position....Latitude 30° South
Longitude 120°30′ West
Azimuth ..................S 115°W
Altitude Intercept....11.9 miles away

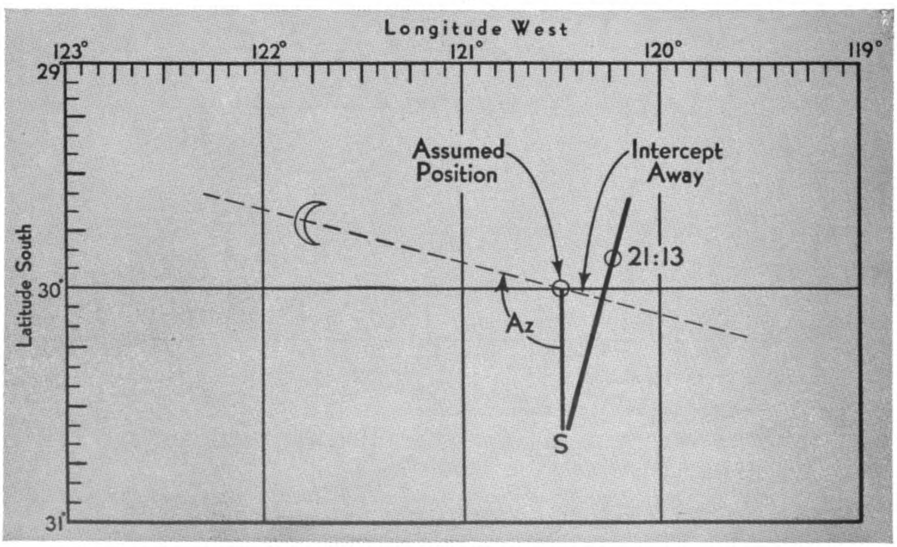


FIG. 124



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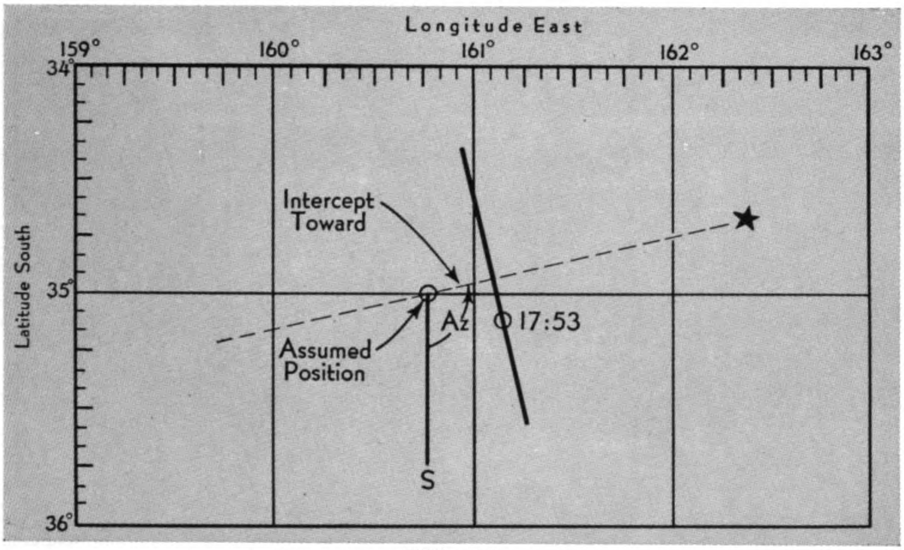


FIG. 125

*Example* No. 4 Planet (Figure 125)

Time of sight..........GCT $17^h53^m10^s$
Assumed position....Latitude 35° South
Longitude 160°47′ East
Azimuth ..................S 103.7°E
Altitude Intercept....17.1 miles toward

## SINGLE LINE OF POSITION

The single line of position, although it definitely locates the aircraft's position in one direction only, can be very useful to the navigator who understands its value and correctly interprets the information which it gives him.

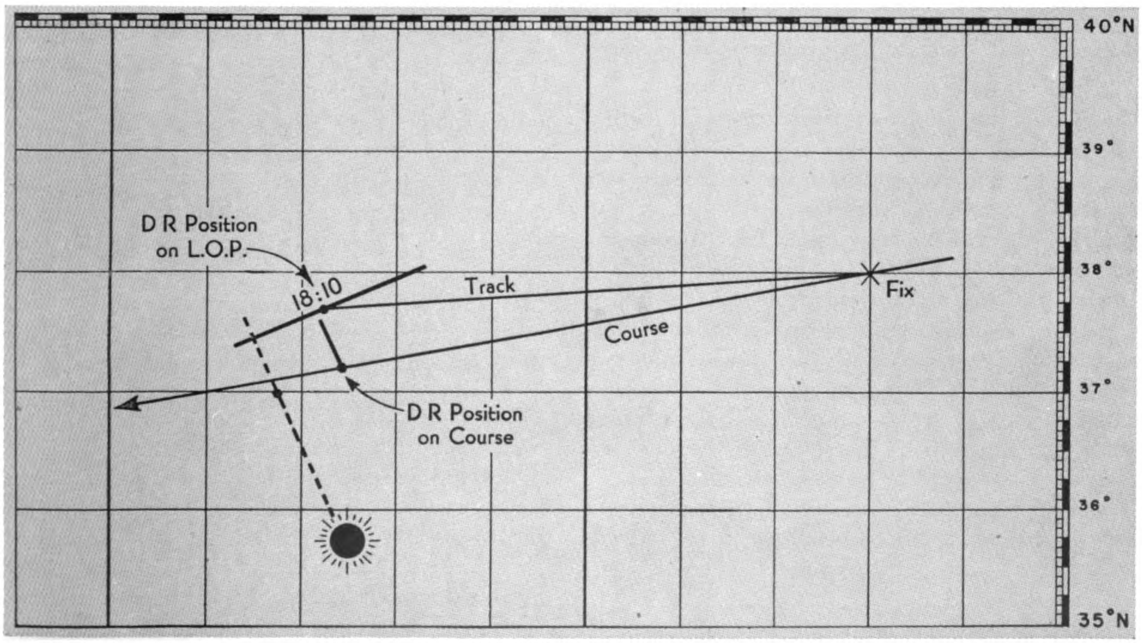


FIG. 126—SINGLE L.O.P. PARALLEL TO COURSE PROVES TRACK



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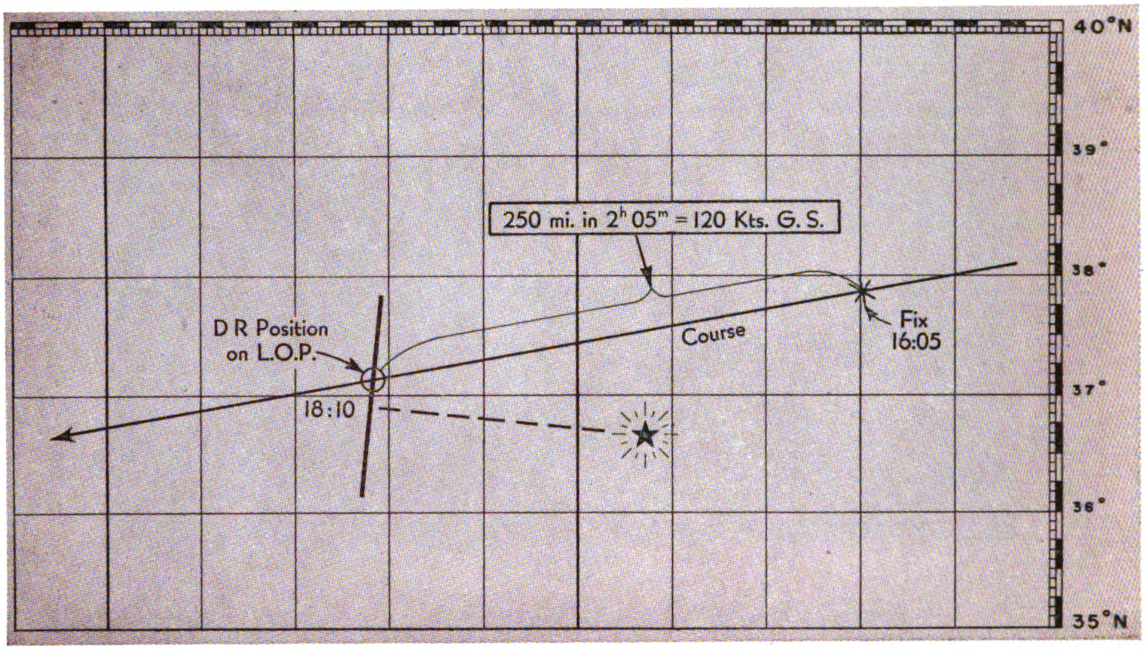


FIG. 127—SINGLE L.O.P. PERPENDICULAR TO COURSE PROVES GROUND SPEED

**Determining Track**—If the single line of position is parallel to the aircraft's course, it will indicate the amount of drift and the track being made good. (Figure 126)

**Determining Ground Speed**—If the single line of position is perpendicular to the aircraft's course, it will indicate the ground speed being made good. (Figure 127)

**Advancing Lines of Position**—The navigator, having plotted a line of position for the instant of observation, quite often finds it advisable to advance or retard the line to a different time. This is possible because, since the aircraft is known to be somewhere on the line of position at the instant of observation, it may be assumed that all points on the line of position are moving as the aircraft moves and at a common rate along the same course, much as would a row of aircraft whose wings were joined together. Therefore, if the line of position is advanced or retarded *along the course* to a dead reckoning position, all the points of the original line of position move in the same direction, and through the same distance. (Figure 128)

Hence to advance (or retard) a line of position to a different time, move the point where it intersects the course line along the course a distance equal to the minutes of ground speed flown, and through this advanced (or retarded) point draw a new line of position parallel to the original line. (Figure 129)

The accuracy of the advanced line of position depends on how accurately the ground speed and track are known. For lines of position advanced or retarded from three to twenty minutes, errors involved are negligible, and the new line may be considered as accurate as the original line of position. However, if the line is advanced more than one hour it may contain appreciable error due to the fact that the dead reckoning ground speed is based upon an estimated wind. Hence, such lines should be used with appreciation of all possible errors of the dead reckoning course and ground speed.

## POSITION FIXES

**Fix by Two Sun Lines**—Often the aerial navigator must depend solely on single position lines (such as sun lines) in order to fix his position. In this procedure, the navigator shoots the sun and obtains single position lines at elapsed intervals which should not be more than one hour apart. During this elapsed interval the sun's azimuth is changing continuously,



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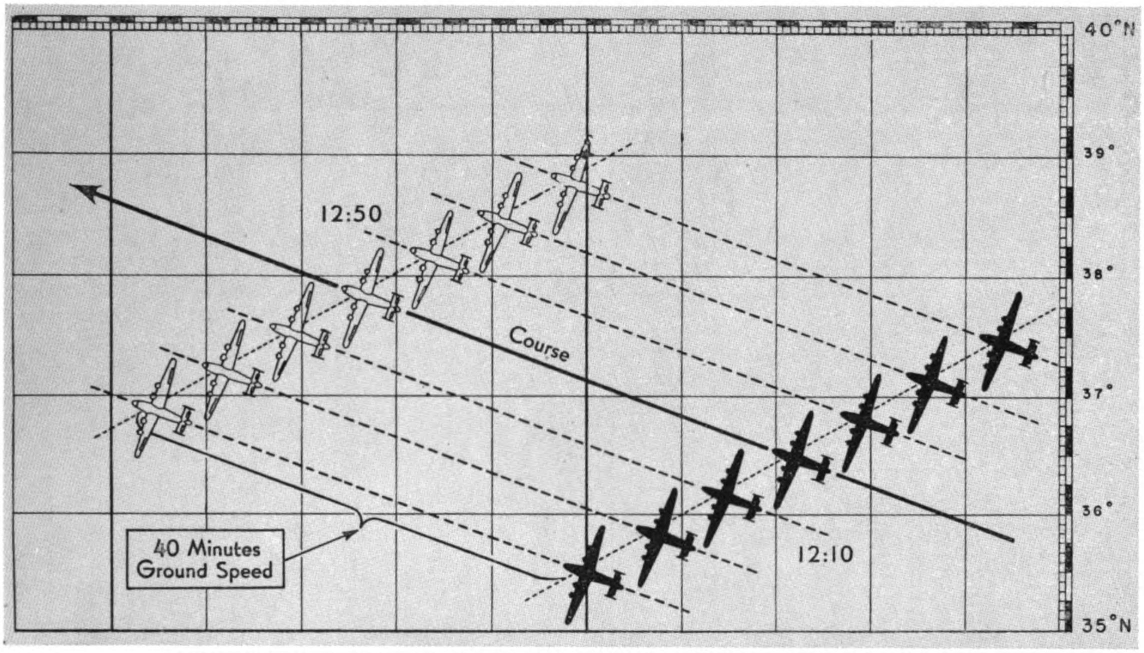


**FIG. 128—ALL POINTS ON L.O.P. MOVE PARALLEL TO COURSE**

which likewise causes the direction of the position line to change. Therefore, by advancing the previous position line to the latest position line, a cross of lines will be obtained which will thus fix the aircraft's position. (Figure 130)

For such a fix to be of any value, the navigator must carefully analyze all possible errors in the track and ground speed used to advance the line of position, because the azimuth change usually is very slight. This type fix is most reliable when the azimuth change is rapid, such

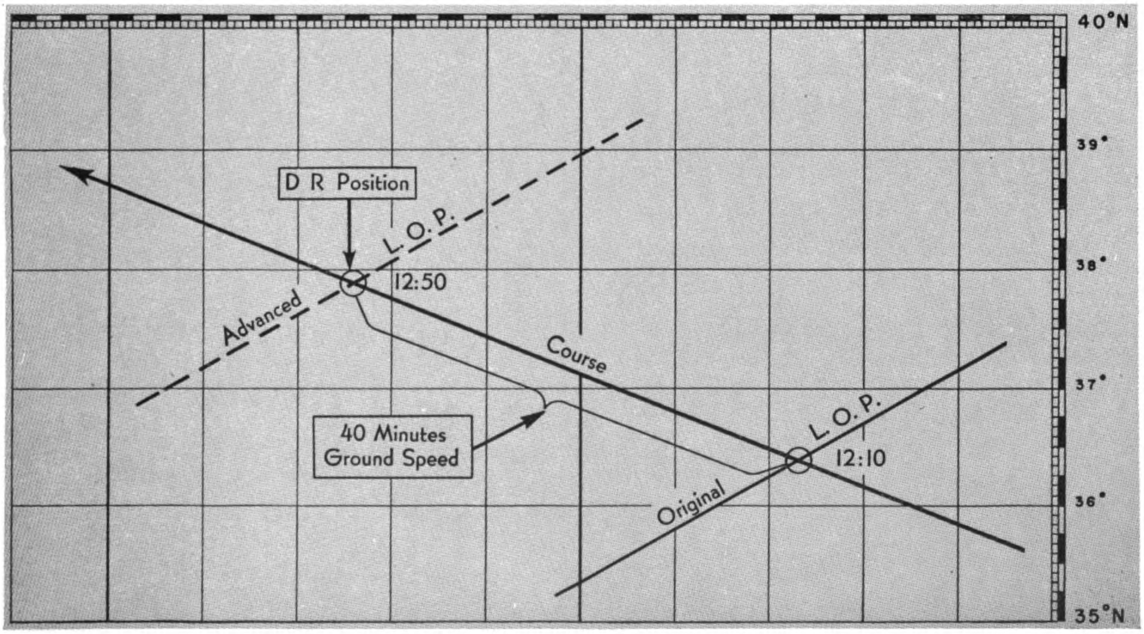


**FIG. 129—ADVANCED L.O.P. DRAWN PARALLEL TO ORIGINAL L.O.P.**



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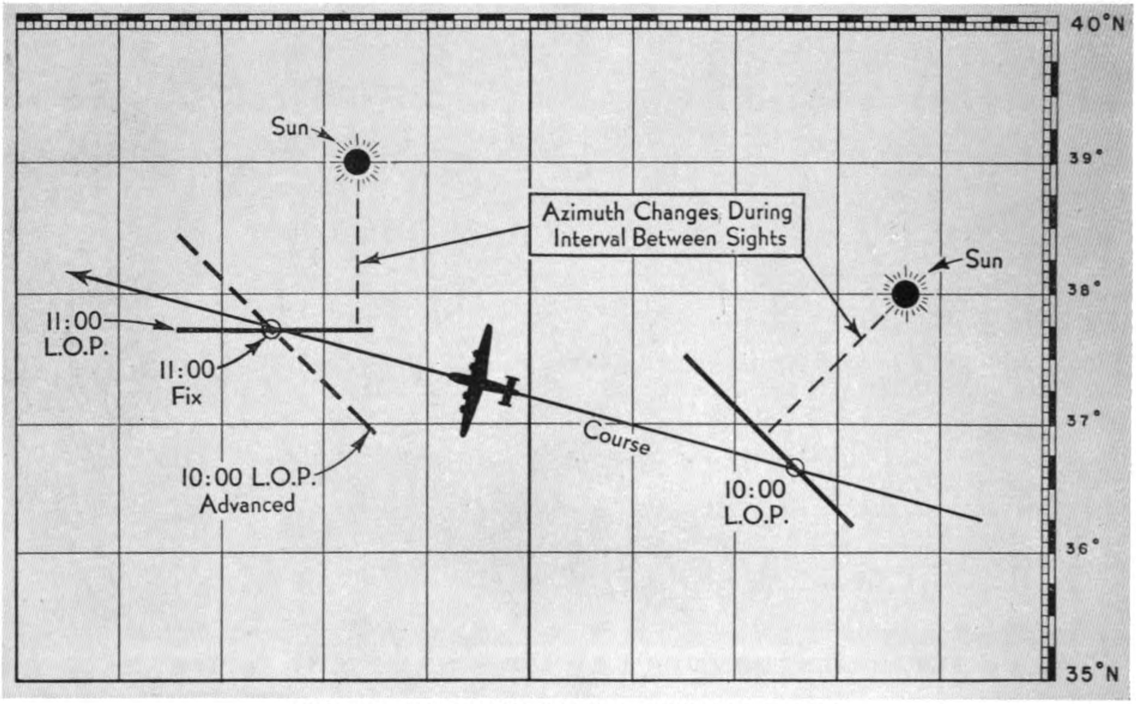


FIG. 130—RUNNING FIX BY TWO SUN LINES

as when the body is near the observer's celestial meridian. When this occurs, the body may be observed at shorter intervals and the resultant angle of "cut" of position lines will be greater.

**Fix by Any Two Position Lines**—Any bearing, such as a visual bearing of a mountain peak or a radio bearing, also provides a position line since it definitely locates the aircraft's po-

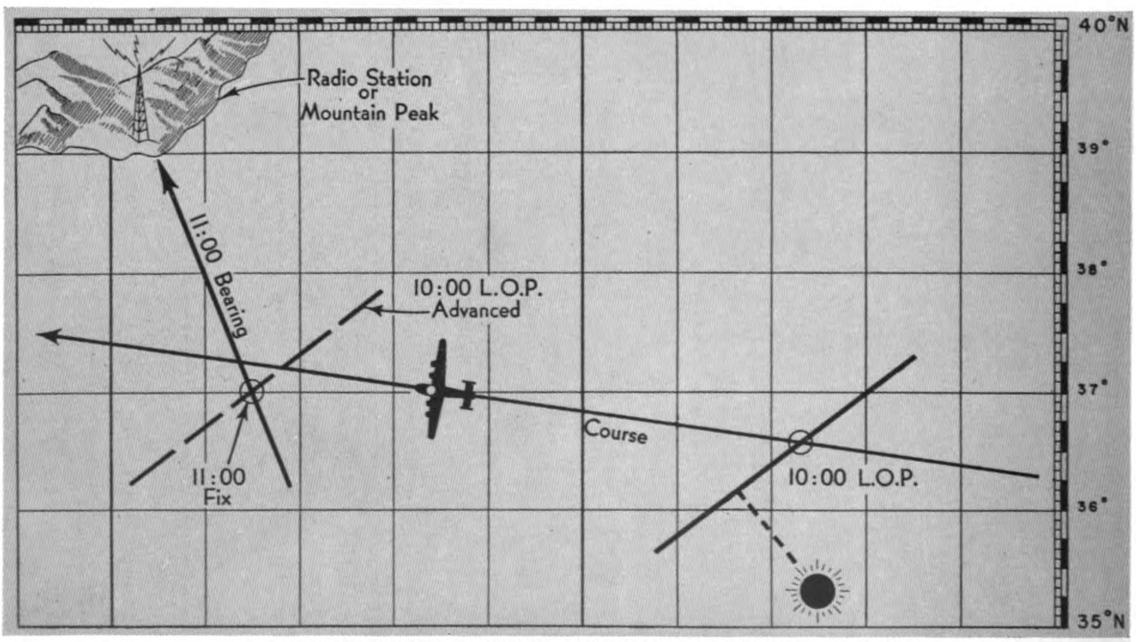


FIG. 131—RUNNING FIX BY ANY TWO POSITION LINES



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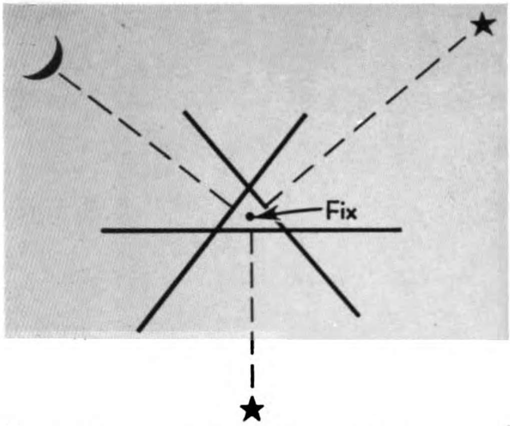


**FIG. 132—POSITION TRIANGLE**

sition in one direction (i.e. somewhere on the bearing line). Therefore, bearings may be advanced to celestial position lines, or celestial position lines may be advanced to bearings in order to obtain a fix. (Figure 131)

**Three Star Fixes**—The three star fix is by far the most desirable and most accurate method of celestial navigation.

To obtain a fix, three celestial bodies whose azimuths differ (by at least 60° if possible) are observed, and the resultant position lines, when plotted on the chart, should intersect at a point or small triangle which definitely locates the aircraft's position. (Figure 132).

Since it is physically impossible to take three sights simultaneously, the observations are taken with as little time interval between as possible. The lines of position are then plotted, and advanced or retarded to a common time. (Figure 133)

In actual practice, as illustrated in Figure 134, the last line of position (11:00) is usually plotted on the chart first. Then, since only the common time fix (11:00) is desired, the earlier lines of position (10:40 and 10:50) are only lightly indicated at their origin, to facilitate their advance to the common time (11:00).

**Track and Ground Speed Between Fixes**—A fix, whether it is a celestial fix or a visual fix, determines the location of the aircraft at the time of the fix. Therefore, when fixes are taken at intervals, the track, ground speed, drift, and wind between the fixes may be easily and accurately determined.

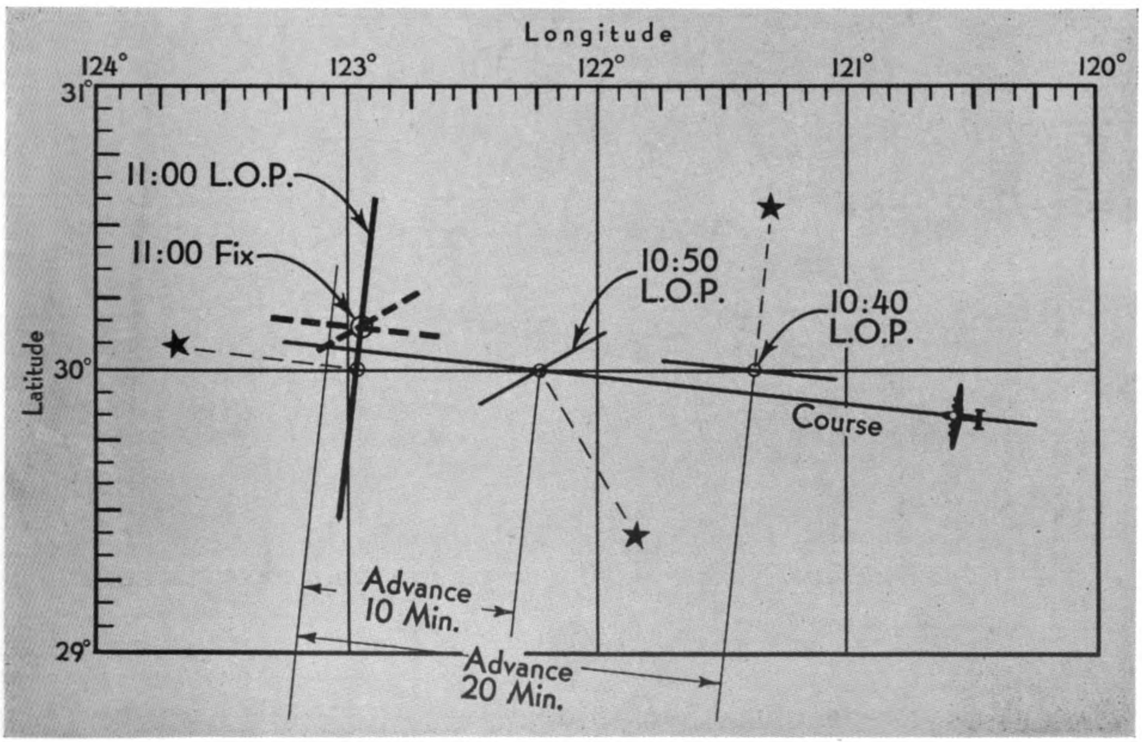


**FIG. 133—THREE STAR RUNNING FIX**



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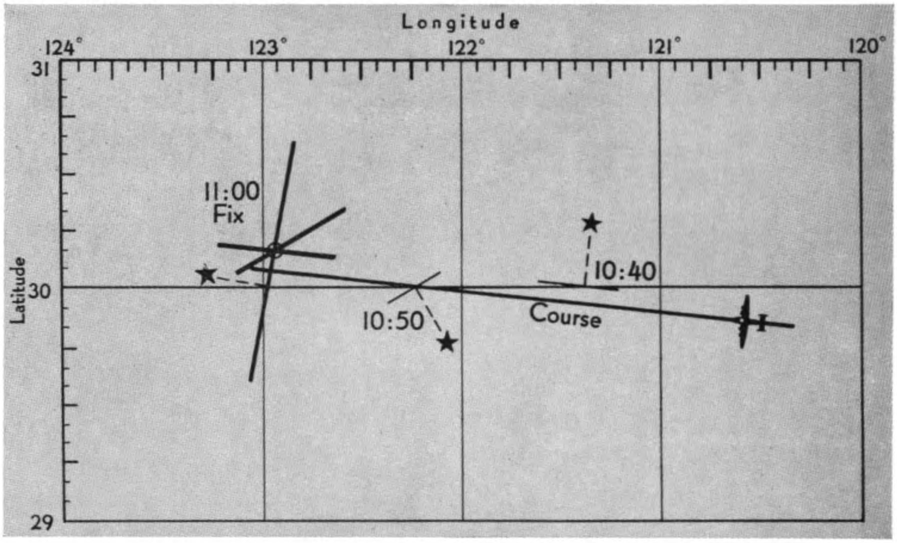


FIG. 134—PRACTICAL PLOTTING OF THREE STAR FIX

The track is determined by a straight line connecting two successive fixes. The ground speed is found by dividing the distance between fixes by the time interval flown.

The wind is then the resultant vector component between the track and ground speed and the true heading and true air speed. (Figure 135)

In actual practice, the track and distance flown between fixes are measured on the chart. The ground speed, drift, and wind are usually solved on the computer.

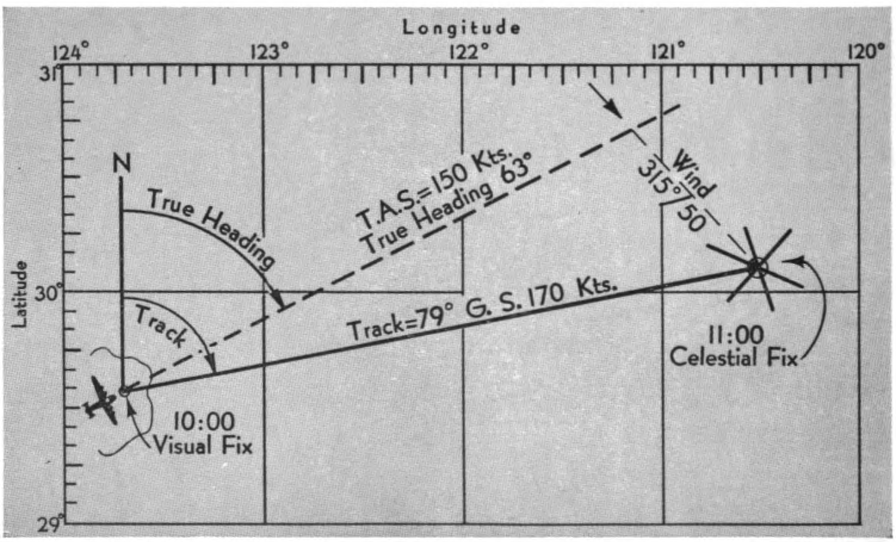


FIG. 135—DETERMINING TRACK, GROUND SPEED AND WIND BETWEEN FIXES

## PROBLEM WORK

No. 26—Plot Problem Work No. 25.



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**PROBLEM WORK NO. 23**

**ASSUMED POSITION—LHA—DECLINATION**

(Find assumed position, LHA and declination.)

| No. | DATE | DR POSITION | | GCT | CELESTIAL BODY | ASSUMED POSITION | | LHA | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. | | | Lat. | Long. | | |
| 1 | 5- 1-43 | 34°10′N | 110°32′E | 22:22:00 | ARCTURUS | | | | |
| 2 | 5- 5-43 | 23°15′S | 172°14′W | 22:14:00 | SUN | | | | |
| 3 | 5-10-43 | 14°21′N | 117°42′W | 20:19:00 | JUPITER | | | | |
| 4 | 5-15-43 | 22°18′N | 178°31′E | 02:19:32 | SUN | | | | |
| 5 | 5-20-43 | 11°01′S | 124°19′E | 19:37:07 | RIGIL KENT. | | | | |
| 6 | 5-30-43 | 14°36′N | 117°51′E | 12:38:00 | PROCYON | | | | |
| 7 | 5- 1-43 | 32°51′N | 168°41′W | 00:31:14 | SUN | | | | |
| 8 | 5- 5-43 | 18°13′S | 104°32′E | 10:52:00 | VENUS | | | | |
| 9 | 5-10-43 | 15°14′S | 168°14′E | 12:15:00 | NUNKI | | | | |
| 10 | 5-15-43 | 32°08′S | 114°39′W | 23:19:00 | MOON | | | | |
| 11 | 5-20-43 | 18°54′N | 127°27′W | 03:16:00 | SPICA | | | | |
| 12 | 5-30-43 | 7°15′S | 92°00′W | 00:10:00 | ALDEBARAN | | | | |
| 13 | 5- 1-43 | 19°43′N | 116°37′W | 05:36:00 | BETELGEUX | | | | |
| 14 | 5- 5-43 | 4°04′N | 152°19′W | 21:50:00 | RIGEL | | | | |
| 15 | 5-10-43 | 16°31′S | 86°49′E | 05:16:00 | CANOPUS | | | | |
| 16 | 5-15-43 | 31°19′S | 178°19′W | 02:16:20 | SUN | | | | |
| 17 | 5-20-43 | 20°14′N | 117°22′W | 02:50:00 | BELLATRIX | | | | |
| 18 | 5-30-43 | 17°51′S | 172°15′E | 23:18:45 | SUN | | | | |
| 19 | 5- 1-43 | 14°19′S | 179°12′W | 03:50:00 | RIGIL KENT | | | | |
| 20 | 5-10-43 | 23°31′N | 162°14′W | 06:53:19 | PROCYON | | | | |



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## PROBLEM WORK NO. 24

## ALTITUDE AND AZIMUTH (H. O. 214)

[Find altitude ($H_c$) and azimuth. Use volume IV, H. O. 214.]

| No. | LATITUDE | DECLINATION | LHA | $H_c$ | AZIMUTH |
|---|---|---|---|---|---|
| 1 | 33°N | 13°48′N | 65°W | | |
| 2 | 36°N | 23°06′N | 48°E | | |
| 3 | 39°N | 11°20′S | 61°E | | |
| 4 | 38°N | 22°40′N | 35°W | | |
| 5 | 34°N | 16°24′N | 41°W | | |
| 6 | 38°S | 57°32′S | 29°W | | |
| 7 | 31°N | 8°43′N | 51°E | | |
| 8 | 35°N | 26°18′S | 40°W | | |
| 9 | 31°N | 19°29′N | 30°E | | |
| 10 | 38°N | 7°24′N | 38°W | | |
| 11 | 31°N | 45°57′N | 26°E | | |
| 12 | 32°N | 45°05′N | 42°W | | |
| 13 | 31°S | 29°56′S | 19°E | | |
| 14 | 36°S | 28°10′N | 29°W | | |
| 15 | 35°N | 5°22′N | 43°E | | |
| 16 | 32°S | 12°15′N | 39°E | | |
| 17 | 33°S | 8°16′S | 40°W | | |
| 18 | 31°N | 16°38′S | 27°E | | |
| 19 | 39°N | 10°52′S | 46°W | | |
| 20 | 32°N | 38°44′N | 28°E | | |



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**PROBLEM WORK NO. 25**

**ASSUMED POSITION—INTERCEPT—AZIMUTH**

(Find assumed position, altitude intercept and azimuth by H. O. 214.)

| No. | CELESTIAL BODY | DATE | GCT | Ho | DR POSITION Lat. | DR POSITION Long. | ASSUMED POSITION | Int. | Az. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | NUNKI | 5-1-43 | 12:18:30 | 19°40′ | 35°02′S | 156°03′E | | | |
| 2 | CANOPUS | 5-5-43 | 05:44:13 | 71°49′ | 35°10′S | 153°29′E | | | |
| 3 | MOON | 5-10-43 | 03:01:35 | 18°31′ | 35°25′S | 154°15′E | | | |
| 4 | SUN | 5-15-43 | 02:58:00 | 29°58′ | 29°50′N | 160°00′W | | | |
| 5 | JUPITER | 5-20-43 | 23:58:36 | 58°02′ | 30°01′N | 158°15′W | | | |
| 6 | ANTARES | 5-20-43 | 10:19:10 | 31°00′ | 30°25′N | 161°12′W | | | |
| 7 | VENUS | 5-10-43 | 06:11:18 | 65°42′ | 39°20′N | 152°28′E | | | |
| 8 | CAPELLA | 5-1-43 | 04:34:35 | 83°04′ | 38°45′N | 151°25′E | | | |
| 9 | SUN | 5-15-43 | 02:15:58 | 69°12′ | 39°12′N | 151°12′E | | | |
| 10 | SUN | 5-5-43 | 15:38:38 | 17°17′ | 32°40′N | 135°45′W | | | |
| 11 | MOON | 5-20-43 | 11:58:31 | 30°09′ | 33°05′N | 136°00′W | | | |
| 12 | MARS | 5-15-43 | 20:32:29 | 27°30′ | 33°15′N | 136°12′W | | | |
| 13 | JUPITER | 5-1-43 | 05:05:05 | 20°43′ | 36°25′S | 145°20′W | | | |
| 14 | MOON | 5-10-43 | 02:24:00 | 34°58′ | 36°05′S | 146°12′W | | | |
| 15 | SUN | 5-5-43 | 19:35:39 | 30°00′ | 35°45′S | 146°50′W | | | |
| 16 | MOON | 5-20-43 | 11:06:00 | 45°30′ | 31°40′S | 155°20′E | | | |
| 17 | PROCYON | 5-15-43 | 08:19:39 | 36°38′ | 31°58′S | 157°01′E | | | |
| 18 | SUN | 5-1-43 | 01:08:00 | 42°39′ | 32°12′S | 156°18′E | | | |
| 19 | MOON | 5-10-43 | 03:32:56 | 25°50′ | 37°45′S | 133°20′W | | | |
| 20 | JUPITER | 5-25-43 | 00:56:38 | 29°59′ | 38°01′S | 135°02′W | | | |



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## PROBLEM WORK NO. 27

## ADVANCING SINGLE LINES OF POSITION

(Plot single line of position and advance required number of minutes or to GCT indicated.)

| No. | DATE | GCT | CELESTIAL BODY | Ho | DR POSITION Lat. | DR POSITION Long. | Az | Intercept | Ground Speed | Track | ADVANCE L.O.P Time | ADVANCE L.O.P N.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5- 1-43 | 06:00:00 | SUN | 49°35′ | 30°44′N | 49°09′E | | | 180 | 270° | 5 Min. | |
| 2 | 5- 5-43 | 13:10:20 | SUN | 32°17′ | 35°14′S | 11°49′E | | | 99 | 135° | 20 Min. | |
| 3 | 5-10-43 | 02:32:06 | SUN | 23°15′ | 37°52′S | 178°40′W | | | 177 | 32° | 45 Min. | |
| 4 | 5-15-43 | 18:45:26 | SUN | 67°30′ | 33°09′N | 82°03′W | | | 110 | 60° | 45 Min. | |
| 5 | 5-20-43 | 15:14:05 | SUN | 34°50′ | 35°17′S | 56°32′W | | | 198 | 253° | 15:30:00 | |
| 6 | 5-30-43 | 09:21:17 | SUN | 30°05′ | 34°57′S | 17°18′E | | | 164 | 350° | 09:30:00 | |
| 7 | 5- 1-43 | 08:27:13 | SUN | 45°01′ | 39°05′N | 8°27′E | | | 120 | 179° | 08:30:00 | |
| 8 | 5- 1-43 | 03:30:00 | MOON | 26°03′ | 33°15′S | 29°52′E | | | 107 | 99° | 10 Min. | |
| 9 | 5- 5-43 | 21:14:30 | MOON | 63°01′ | 32°49′N | 98°10′W | | | 154 | 177° | 21:30:00 | |
| 10 | 5-10-43 | 02:57:05 | MOON | 23°32′ | 37°14′S | 117°05′W | | | 114 | 240° | 03:00:00 | |
| 11 | 5-20-43 | 23:45:01 | MOON | 28°18′ | 35°51′N | 10°30′W | | | 202 | 38° | 24:00:00 | |
| 12 | 5-30-43 | 03:05:50 | MARS | 33°01′ | 34°51′S | 117°10′E | | | 107 | 260° | 03:10:00 | |
| 13 | 5- 1-43 | 02:00:47 | VENUS | 42°16′ | 35°21′N | 117°57′W | | | 89 | 42° | 02:10:00 | |
| 14 | 5- 5-43 | 10:10:00 | JUPITER | 41°03′ | 33°12′N | 150°40′E | | | 180 | 355° | 10:30:00 | |
| 15 | 5-10-43 | 09:31:10 | MARS | 27°01′ | 37°05′N | 70°15′W | | | 160 | 180° | 09:40:00 | |
| 16 | 5-20-43 | 15:36:40 | POLARIS | 36°05′ | 35°50′N | 152°21′W | | | 119 | 180° | 15:40:00 | |
| 17 | 5-30-43 | 18:23:07 | ARCTURUS | 54°01′ | 36°05′N | 14°07′E | | | 148 | 90° | 18:30:00 | |
| 18 | 5- 1-43 | 08:42:50 | VEGA | 54°09′ | 38°44′N | 117°05′W | | | 89 | 270° | 08:50:00 | |
| 19 | 5- 5-43 | 21:00:58 | ALTAIR | 26°30′ | 32°57′S | 169°40′E | | | 107 | 106° | 21:06:00 | |
| 20 | 5-10-43 | 15:16:00 | DUBHE | 49°30′ | 35°07′N | 117°50′E | | | 126 | 136° | 15:30:00 | |



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**PROBLEM WORK NO. 28**

**THREE STAR FIXES**

GROUND SPEED 180 knots—TRACK 242°

(Find line of position for each star. Advance lines of position to obtain "FIX" for time of third star in each group.)

| No. | DATE | GCT | CELESTIAL BODY | $H_o$ | DR POSITION | FIX |
|---|---|---|---|---|---|---|
| 1 | 5- 1-43 | 01:04:20 | VEGA | 46°39′ | LAT. 32°10′N LONG. 8°41′W | |
| | | 01:10:00 | DENEB | 26°28′ | | |
| | | 01:15:12 | ALPHECCA | 83°04′ | | |
| 2 | 5- 5-43 | 04:13:41 | RIGEL | 62°31′ | LAT. 32°14′S LONG. 137°14′E | |
| | | 04:19:30 | CANOPUS | 59°10′ | | |
| | | 04:26:30 | ALDEBARAN | 41°25′ | | |
| 3 | 5-10-43 | 15:40:00 | CAPELLA | 56°39′ | LAT. 35°09′N LONG. 17°14′E | |
| | | 15:50:00 | POLARIS | 35°15′ | | |
| | | 16:00:00 | ALDEBARAN | 36°39′ | | |
| 4 | 5-15-43 | 21:50:00 | RUCHBAH | 61°34′ | LAT. 31°17′N LONG. 180°00′ | |
| | | 21:52:00 | MARS | 44°47′ | | |
| | | 21:55:00 | ENIF | 33°28′ | | |
| 5 | 5-20-43 | 09:51:40 | ARCTURUS | 69°31′ | LAT. 39°21′N LONG. 175°43′W | |
| | | 09:58:35 | DUBHE | 54°17′ | | |
| | | 10:07:37 | REGULUS | 29°02′ | | |
| 6 | 5- 5-43 | 17:01:59 | DENEB | 50°24′ | LAT. 32°19′N LONG. 120°05′W | |
| | | 17:03:06 | FOMALHAUT | 25°58′ | | |
| | | 17:05:02 | ALTAIR | 27°47′ | | |
| 7 | 5-20-43 | 14:31:48 | DUBHE | 47°08′ | LAT. 35°51′N LONG. 125°11′E | |
| | | 14:37:00 | SPICA | 38°37′ | | |
| | | 14:40:55 | DENEBOLA | 43°25.5′ | | |
| 8 | 5-10-43 | 04:11:41 | CAPELLA | 33°30′ | LAT. 31°17′N LONG. 140°02′W | |
| | | 04:16:50 | POLLUX | 58°14′ | | |
| | | 04:19:50 | PROCYON | 45°27′ | | |



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**PROBLEM WORK NO. 29**

**TRACK AND GROUND SPEED BETWEEN FIXES**

C.A.S. = 157 knots, ALTITUDE = 7000', TEMPERATURE = +10°C, T.A.S. = ................?

(Plot star sights on a small scale chart, I.C. = 0°. Advance or retard lines of position to obtain fix for time of third sight listed in each group.)

FIND TRACK AND GROUND SPEED MADE GOOD FROM PREVIOUS FIX.

CALCULATE DRIFT AND WIND BETWEEN FIXES.

ALTER TRUE COURSE AS INDICATED.

ESTIMATE TRUE HEADING USING PREVIOUS WIND, GIVEN OR CALCULATED.

| No. | GCT | TYPE OF FIX | POSITION | | TRACK | GROUND SPEED | DRIFT | WIND | TRUE HEADING |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. | Long. | | | | | |
| 1 | TRUE COURSE 242° | | | | | | | | |
| | 07:05 | Visual | 37°50'N | 122°29'W | 242° | | 0° | 0° | 242° |
| 2 | TRUE COURSE 242° | | | | Star sights taken: | | | | |
| | | | | KOCHAB | GCT | 08:32:00 | $H_s$ 50°34' | | |
| | | | | ALPHECCA | GCT | 08:36:00 | $H_s$ 76°31' | | |
| | | | | VEGA | GCT | 08:40:00 | $H_s$ 44°30' | | |
| | 08:40 | Celestial | | | | | | | |
| 3 | TRUE COURSE 247° | | | | Star sights taken: | | | | |
| | | | | ANTARES | GCT | 09.27:00 | $H_s$ 28°15' | | |
| | | | | RASALAGUE | GCT | 09:34:00 | $H_s$ 54°37' | | |
| | | | | ARCTURUS | GCT | 09:30:00 | $H_s$ 69°00' | | |
| | 09:30 | Celestial | | | | | | | |
| 4 | TRUE COURSE 249° | | | | Star sights taken: | | | | |
| | | | | POLARIS | GCT | 10:13:00 | $H_s$ 32°46' | | |
| | | | | ALTAIR | GCT | 10:16:00 | $H_s$ 31°24' | | |
| | | | | DENEB | GCT | 10:20:00 | $H_s$ 36°14' | | |
| | 10:20 | Celestial | | | | | | | |
| 5 | TRUE COURSE 232° | | | | Star sights taken: | | | | |
| | | | | SABIK | GCT | 11:32:00 | $H_s$ 42°44' | | |
| | | | | ALIOTH | GCT | 11:38:00 | $H_s$ 40°27' | | |
| | | | | SPICA | GCT | 11:35:00 | $H_s$ 22°35' | | |
| | 11:35 | Celestial | | | | | | | |



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## CELESTIAL REVIEW EXAMINATION NO. 2

1. Draw Celestial Sphere. Show all parts you know.

2. Define:

   (a) Vertical Circle
   (b) Hour Circle
   (c) Azimuth
   (d) Equinoctial
   (e) Declination
   (f) Altitude
   (g) Local Hour Angle
   (h) Ecliptic
   (i) Sidereal Hour Angle
   (j) Geographical Position

3. Show the following by hour angle diagrams:

   (a) GHA Sun 120°
   Long. 40° East
   LHA Sun

   (b) GHA Aries 60°
   SHA Star 180°
   Long. 80° East
   GHA Star
   LHA Star

4. Solve:

   (a) On January 2nd at Long. 120° West, the LCT is 18:31. What is the time and date in Greenwich?

   (b) On July 15, when GCT is 22:16, what is the Local Civil Time and date at Long. 118° East?

5. Honolulu ZD = + 9½
   Canton ZD = +10½
   Fiji ZD = —12

   (a) An aircraft leaves Honolulu at ZT 10:00 A. M., August 3rd, arriving at Canton 9 hours and 30 minutes later. What is local time and date of arrival?

   (b) An aircraft leaves Canton at ZT 12:00 noon, January 5th, arriving at Fiji 6 hours later. What is the local zone time and date of arrival?

6. May 1, 1943, GCT $11^h20^m22^s$: Find GHA and declination of Sun, Moon and Sirius.

7. The following altitudes were obtained with a bubble sextant of I.C.—6′, at height of 8000 ft., May 10, 1943:

   Sun 30°20′ Venus 60°15′ Altair 20°12′ Moon 28°35′

   What are the true altitudes?

8. On May 20, 1943, GCT $11^h20^m20^s$ in longitude 145°18′ West, the altitude of Polaris (using a bubble sextant) was found to be 32°15′. If the height of the plane was 5000 ft. and the I.C. 0°, what was the latitude of the observer?

9. At DR latitude 30°15′ North, longitude 70°25′ West, on May 30, 1943, at a height of 7000 ft., I.C. 0°, and GCT $03^h16^m07^s$, the observed altitude of Antares was 30°07′. What are the altitude intercept and azimuth?

10. (a) Describe the process of forming the bubble in a Pioneer octant.

    (b) In what relation are the bubble and the body for accurate sights? For inaccurate sights?



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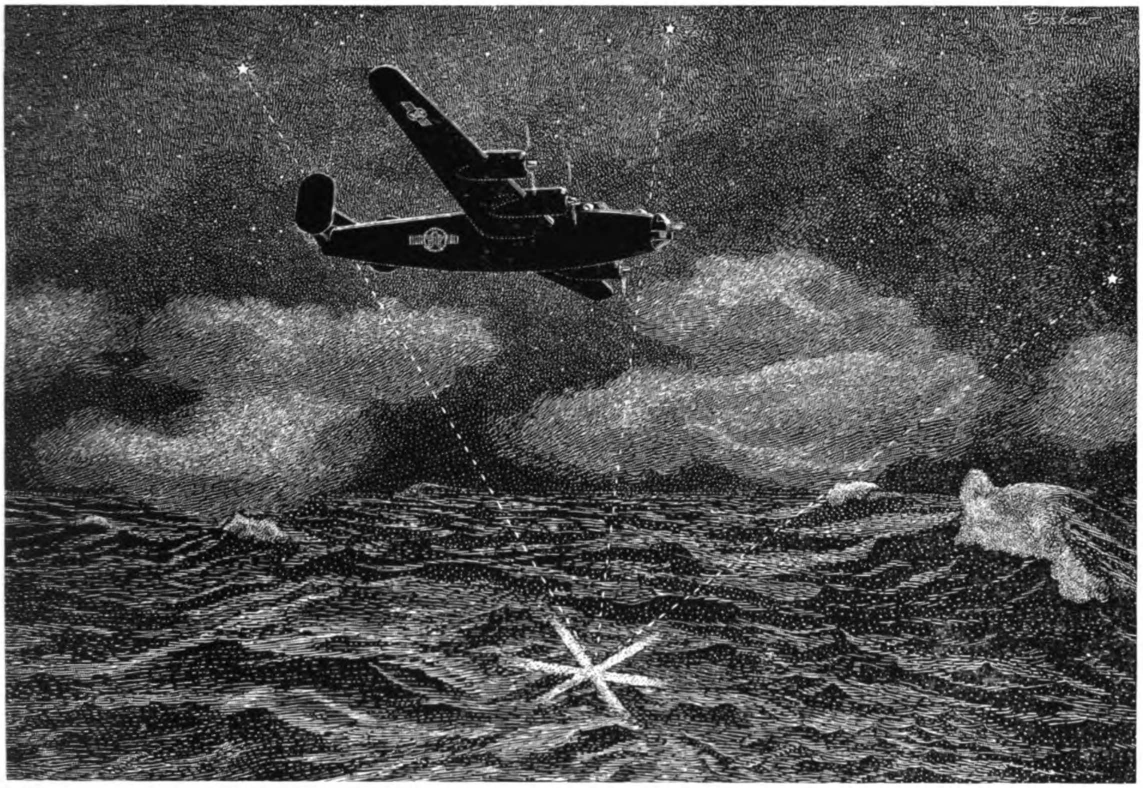

# ☆ 10 ☆

# STARS AND THE WEATHER

A WORKING knowledge of the stars is easy to acquire, yet few people make an effort to become familiar with them. The fact that the stars, to the average observer, appear so countless and complex in their arrangement probably accounts for the general ignorance about stars and constellations. As a result, most people view the night sky with the same awe and perplexity with which they might view some complicated maze.

It is true that the thousands of stars which may be seen at a single glance do appear to be a complicated maze. However, on examining the sky more closely, the observer will note that a few stars—and only a few—are relatively bright, and because of their unusual brilliance they appear to stand out prominently from all the other stars. Only these few bright stars are used in navigation. Therefore, it is very important that the aerial navigator be able to recognize them quickly, because they are literally the tools of his trade.

The astronomer, working in behalf of the navigator, has calculated and tabulated in the Air Almanac the positions in the celestial sphere of the 55 brightest stars and five planets most suitable for observation, so that the navigator may compute from these 60 known celestial positions the location of his aircraft. Of these 60 stars and



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planets which are tabulated in the Air Almanac—an infinitely small total compared to the innumerable stars seen at night—the author has used not more than 34 for navigation during his last 500,000 miles of travel.

## IDENTIFICATION BY GROUPS

Knowing that only a few of the celestial bodies are needed for navigational purposes, the first step in learning these few is to obtain some good chart of the sky, such as that shown in Figure 136, taken from the Air Almanac. In gaining this knowledge, as in learning the parts of a complicated airplane structure, one may divide the stars into groups, or individual "sub-assemblies of the sky." For a start, Orion's Belt and Sword and the bright stars close by may be considered.

**First Group**—"Orion's Belt and Sword" (See Group Chart, Figure 137)—The constellation of Orion is easily recognized as a perfectly shaped little dipper. The three brightest stars, which usually are drawn as the belt in Orion, form the bottom of the dipper. This group, definitely recognized in the sky, may be used as a starting point for identifying other nearby stars.

Notice, for instance, that seven bright stars appear to form a circle around Orion; they are Rigel, Sirius, Procyon, Pollux, Castor, Capella, and Aldebaran. Try to learn these stars in this order, and then study each star to learn its individual characteristics.

1. *RIGEL* is just in front of the open end of the dipper.

2. *SIRIUS* is the brightest star in the sky and is located between Rigel and Procyon.

3. *PROCYON* is a very bright star. Nearby is a much dimmer, but easily seen sister star. Also, Procyon is located between Sirius and the sister stars, Pollux and Castor.

4. and 5. *POLLUX* (4) and *CASTOR* (5) are known as sister stars because they are of nearly equal brightness and very close together. Pollux, the brighter, is nearer Procyon.

6. *CAPELLA* is nearly as bright a star as Sirius. It has three little stars nearby in the shape of a triangle. Also, at a little greater distance are four other stars which, together with Capella, form a pentagon.

7. *ALDEBARAN* is a bright, reddish-colored star which forms, with four stars nearby, a perfect letter *A*.

Inside this group of stars, and near the bottom of the dipper, are two other very bright stars, Betelgeux and Bellatrix. Betelgeux is the brighter and has a reddish color.

After these stars have been learned and can be easily located in the sky, the observer will be able to find and name many other stars by their positions relative to this group.

For instance, assume that a very bright star is visible and its name is desired. With relation to known stars, it lies in a line with Procyon and Sirius. It appears to be a little farther away from Sirius than is Procyon, and not quite in a direct line but, rather, slightly offset in a direction away from Orion. Looking at the star chart (Figure 136) the name of this star is determined to be Canopus.

*CANOPUS* is the second brightest star in the sky.

This same procedure may be used to locate a star in the sky by use of the star chart (Figure 136). Suppose it is desired to find Regulus in the sky. Using the stars already known, the star chart indicates that Regulus is in direct line with Procyon and the three stars forming the belt of Orion.

*REGULUS* also is distinguished by the fact that it appears as the brightest star in the handle of a small sickle, formed by four dimmer stars nearby.

**Note:** In describing these stars, the author is endeavoring to record the exact line of reasoning followed when trying to identify the stars in flight. On the charts, and especially the group charts, they appear easy to find, but unless they are definitely located with relation to others known, they may prove difficult to identify.

**Second Group**—"Big Dipper and Associated Stars" (See group chart, Figure 138)—The Big Dipper is perhaps the easiest constellation to recognize. It is formed by seven stars: Alkaid, Mizar, Alioth, Megrez, Phecda, Merak, and Dubhe. Of these seven, Alkaid, Mizar, and Alioth in the handle, and Dubhe at the end of the cup are the best for navigation. The declination of the Big Dipper is above 50° North, therefore, if the navigator is above 40° North latitude the Big Dipper would never set below the horizon but would appear to revolve en-



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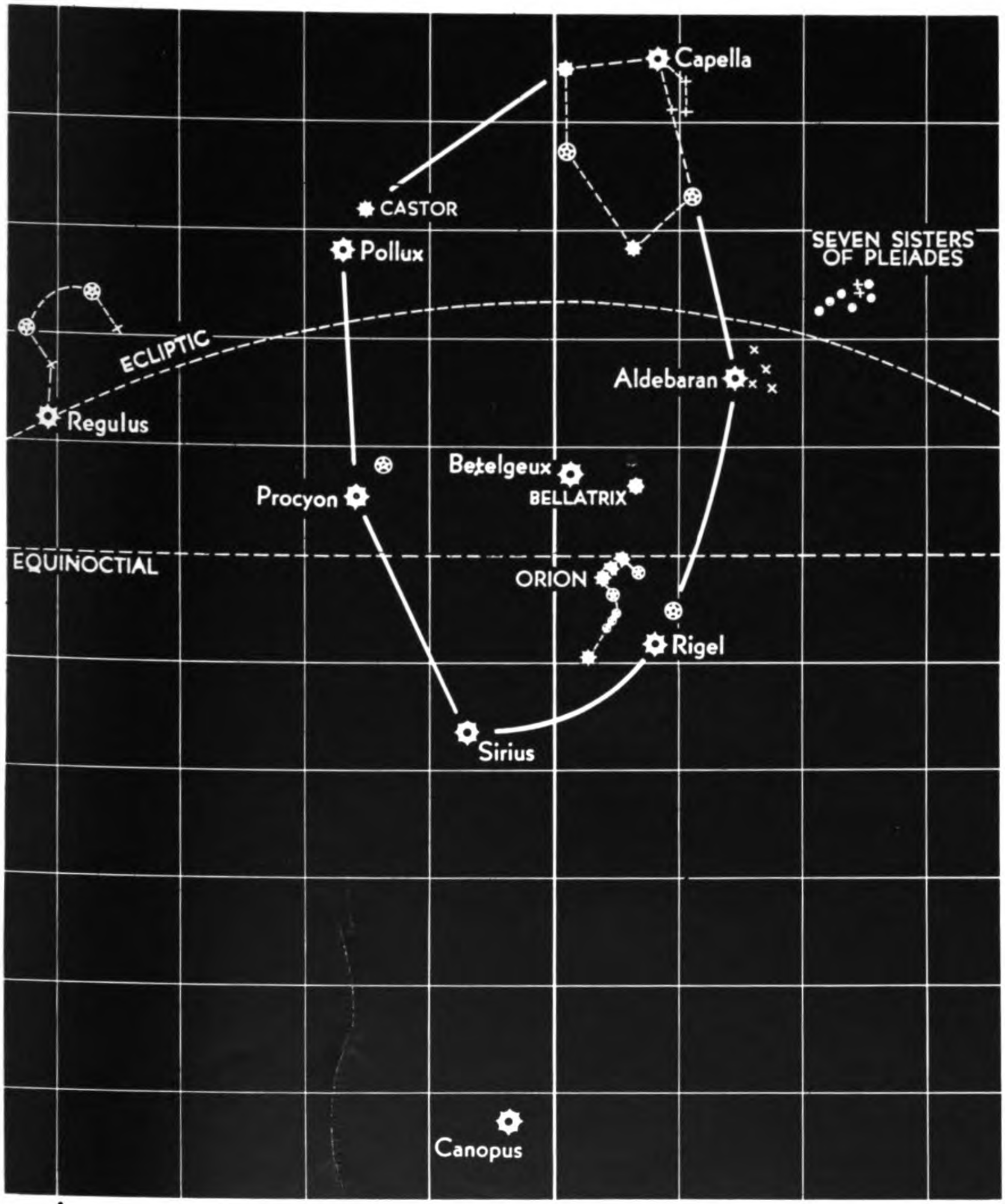


FIG. 137—"ORION'S BELT AND SWORD" GROUP

tirely around the North pole, due to the earth's daily rotation. At one time the Dipper might be seen right side up, as though filling, and then twelve hours later upside down, as though emptying.

To the astronomer, the Big Dipper is known as Ursa Major, but to mariners, for as long as they have sailed in the Northern hemisphere, the Big Dipper is the North pole indicator. This is because the two stars in the cup, Merak and Dubhe, known as the pointers, point almost directly to Polaris.

*POLARIS* is the North pole star. Actually it is about 1° from the true North celestial pole.



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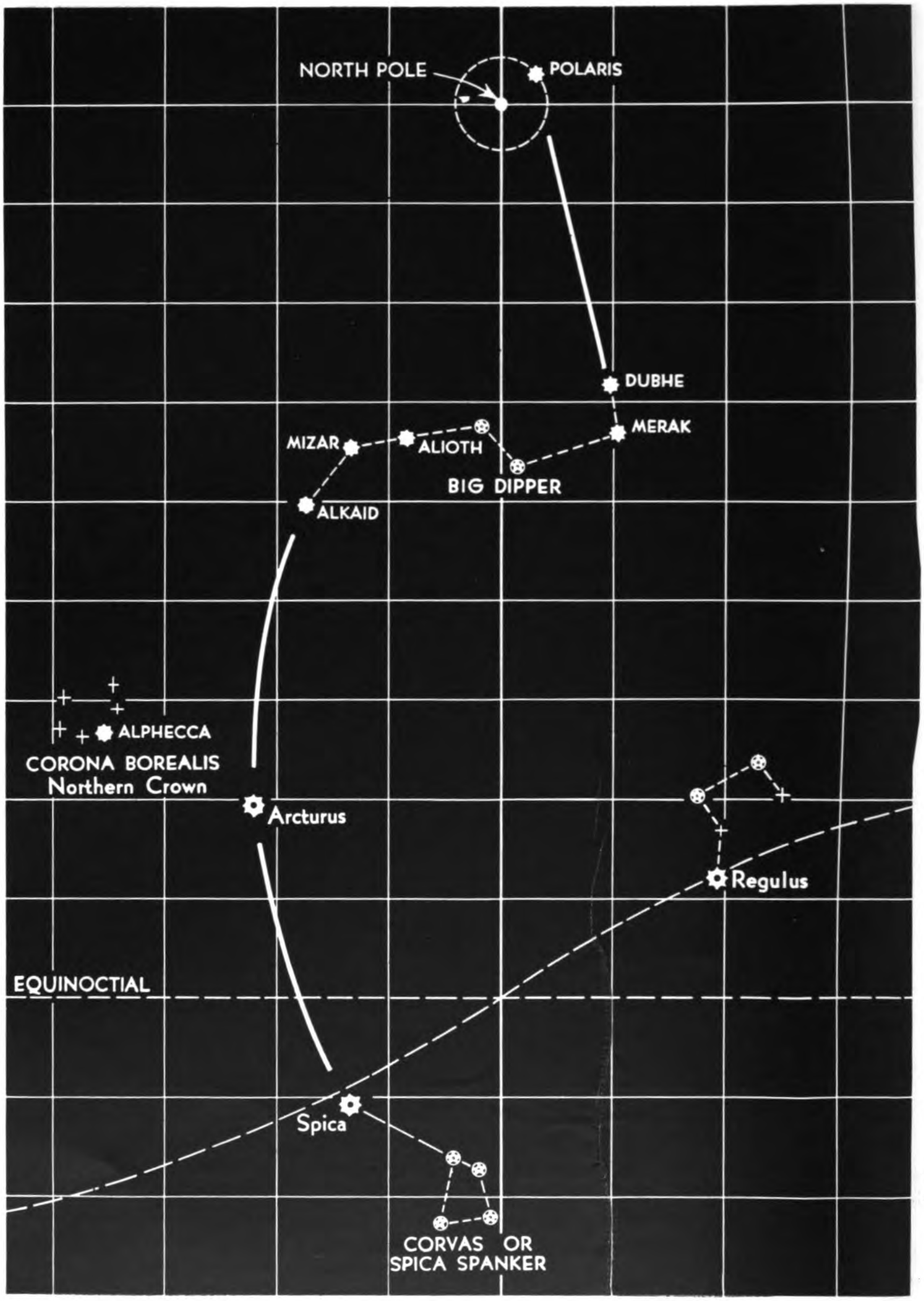


FIG. 138—"BIG DIPPER" GROUP



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*ARCTURUS* and *SPICA* are two very bright stars which may be found by following the curve of the Big Dipper's handle on across the sky. First seen is Arcturus and then Spica. The distance of Spica from Arcturus appears to be very nearly equal to the distance of Arcturus from the end of the handle.

*SPICA* also may be identified by the constellation Corvus. Corvus is sometimes called Spica Spanker as it resembles a ship's spanker sail. The two stars at the top of the sail point to Spica.

*ALPHECCA* is the bright star in the constellation Corona Borealis, known as the Northern Crown. Corona Borealis is easily identified by its shape, which resembles a crown, and may be found by searching the skies northwest of Arcturus.

**Third Group**—"Great Right Triangle" (See group chart, Figure 139)—The Great Right Triangle is formed by the three very bright stars Altair, Vega, and Deneb.

*ALTAIR* is identified by two dimmer stars, which are located on either side of it in a straight line pointing directly toward Vega.

*VEGA* is the bright star at the right angle of the great triangle. It may be identified further by two dimmer stars close by, each of which points to an adjacent angle of the great triangle, and which with Vega form a tiny right triangle.

*DENEB* at the third angle of the great triangle appears slightly dimmer than either Altair or Vega. It also may be identified by two dimmer stars nearby. Each of these stars points to an adjacent angle of the great triangle and form with Deneb a medium-sized equilateral triangle.

**Fourth Group**—"Square of Pegasus" (See group chart, Figure 139)—All of the stars in this group are of medium brightness, but they are easily recognized in the sky and are useful in placing other stars. The four stars Alpheratz, Scheat, Markab, and Algenib, equally distant from one another, form a great square. Sometimes, however, this constellation is called "The Kite" as there are three other stars lined up with one corner of the square which makes the Square of Pegasus resemble a kite and tail.

*ALPHERATZ*, the star in the tail corner and *MARKAB*, in the opposite corner are tabulated in the Air Almanac, and are thus useful for navigation.

The Square of Pegasus identifies Fomalhaut and Deneb-Kaitos.

*FOMALHAUT* is in line with Scheat and Markab.

*DENEB-KAITOS* is in line with Alpheratz and Algenib.

*ENIF* affords another example of finding a star by lining it up with stars already known, as it is in line with, and halfway between, Altair and Markab.

These four star groups include most of the useful navigation stars. If the student learns them well, he should have little difficulty in identifying the other bright stars in the sky.

**Constellation Groups**—There are a few other stars often used in navigation which may be easily identified by their own constellation characteristics, as was Alphecca in Corona Borealis, without resort to grouping. These are, in part:

1. *CAPH, SCHEDIR,* and *RUCHBAH* in the constellation Cassiopeia. (See star chart, Figure 136). Cassiopeia is a northern constellation in the shape of a W, M, or a chair and is sometimes called the W, the M, or The Chair depending on its appearance to the observer as it changes position in the sky.

2. *NUNKI* and *KAUS-AUSTRALIS* in the constellation Sagittarius. Sagittarius is a Southern constellation near the ecliptic having the appearance of a little dipper.

3. *RIGIL KENTAURUS* and the *SOUTHERN CROSS*. In the Southern Cross (*CRUX*) the two stars tabulated in the Air Almanac are $\beta$ and $\gamma$ Crucis, identified on the chart by the Greek letters $\beta$ (*BETA*) and $\gamma$ (*GAMMA*). Rigil Kentaurus and $\beta$ Kentaurus are called the Southern Cross pointers, as they point directly to the Southern Cross.

## IDENTIFICATION BY H. O. 214

Sometimes flight conditions arise where it is necessary for the navigator to take a sight of a celestial body which he is unable to identify by the usual method of its relation to nearby stars. For example, after flying under an overcast sky for several hours the navigator sights a single celestial body through a break in the clouds. In such a case the body may be identified by reference to any altitude-azimuth table or star finder if the altitude and azimuth of the body and the Greenwich civil time are known.



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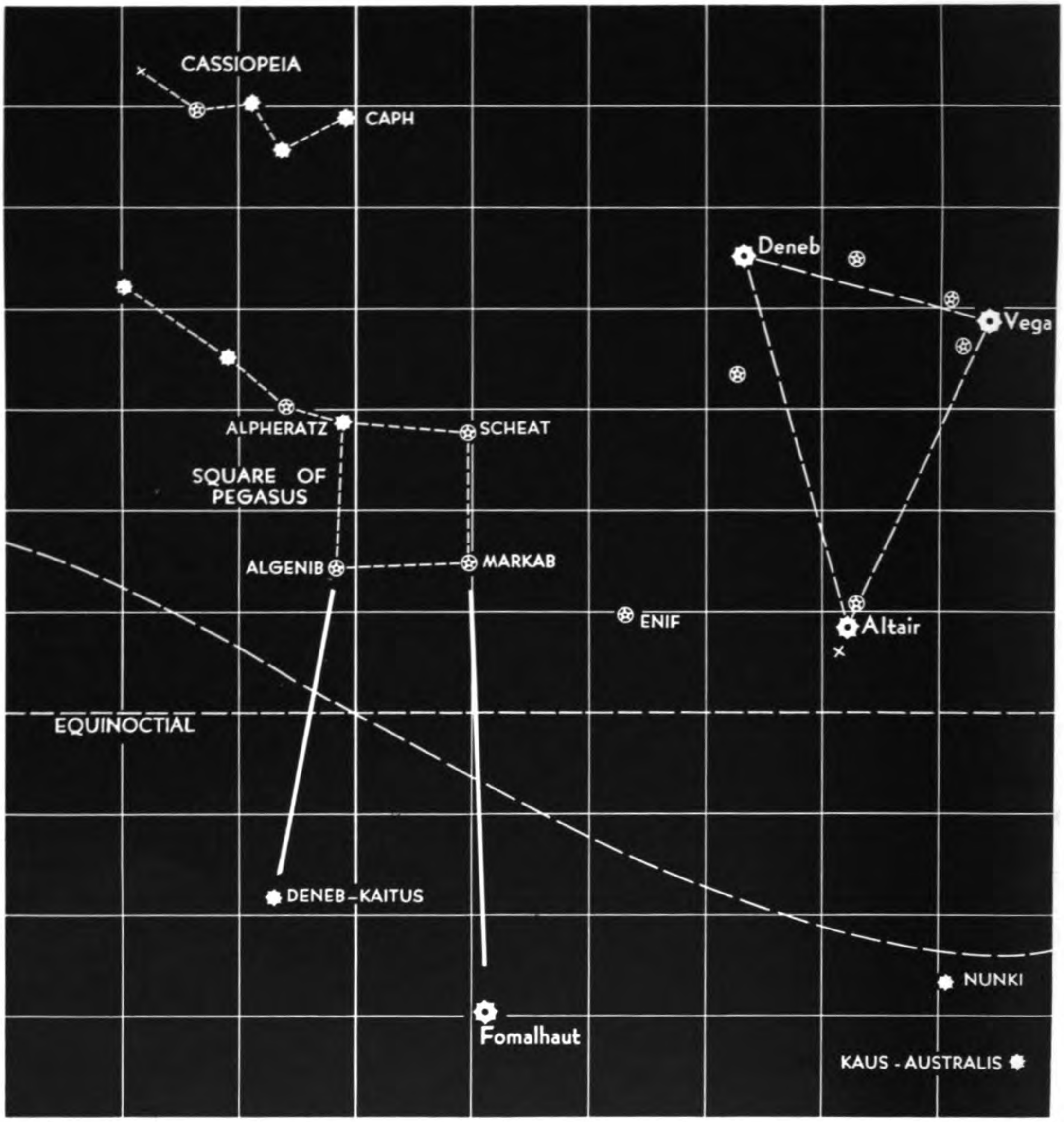


**FIG. 139—"GREAT RIGHT TRIANGLE" AND "SQUARE OF PEGASUS" GROUPS**

**The Procedure** using H. O. 214 is as follows:

a. Observe altitude of the body.

b. Note exact GCT.

c. Estimate the body's true bearing and convert true bearing to azimuth (Figure 140).

d. Enter Star Identification Table H. O. 214, which immediately follows the proper latitude (latitude of the observer), with the altitude and azimuth of the body, and extract tabulated values of approximate LHA and declination. The LHA is tabulated from 0° to 180° East or West. The azimuth name determines the name of the tabulated LHA. If the azimuth is East, the LHA is East because the body is rising. If the azimuth is West, the LHA is West because the body is setting. Tables show declination North or South.



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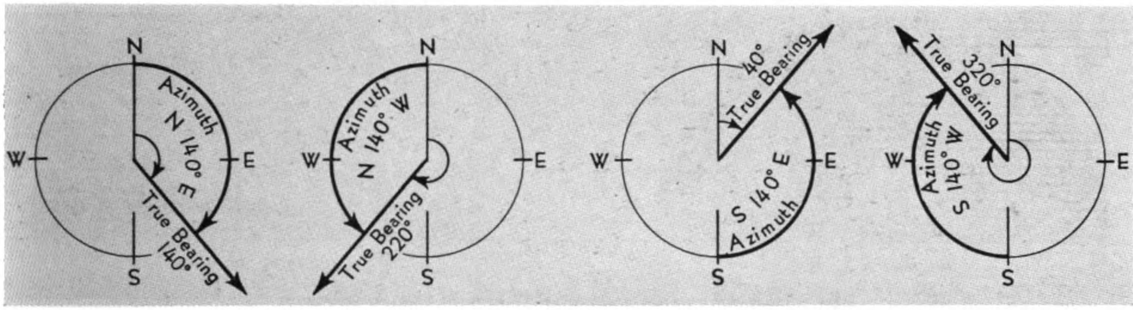


**FIG. 140—AZIMUTH MEASURED FROM ELEVATED POLE**

e. Convert tabulated LHA if East to LHA West by subtracting LHA East from 360° (360° — LHA East = LHA West).

f. Apply DR longitude to LHA West to obtain GHA body.

GHA = LHA West + West longitude / — East longitude

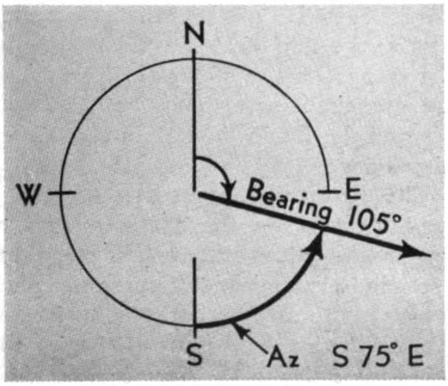


**FIG. 141—$Z_n$ 105° = Az S 75° E**

g. Extract GHA ♈ from Air Almanac for the exact GCT of observation.

h. Find SHA body by subtracting GHA ♈ from GHA body (add 360° to GHA body if necessary).

i. Enter Air Almanac, inside back cover, with SHA body and declination. Extract name of star whose coordinates are nearest to calculated SHA and declination.

*Example*: (Solution of star identification problems is simplified by the use of some such form as that employed below).

May 30: A navigator obtains an altitude of an unknown celestial body of 67°26′ at $07^h52^m00^s$ GCT. With the aid of the pelorus (instrument for measuring a bearing) he estimates its true bearing to be 105°.

DR position = latitude 32°16′S, longitude 117°28′W.

$Z_n$ = 105°; Az = S 75° E (Figure 141).

---

$H_o$ = 67°26′ Enter H. O. 214 Declination = 35°S
$Z_n$ = 105° (Lat. = 32°S) LHA = 26°E
Az = S 75°E

(360° — 26°E = LHA 334°W)

| | | | |
|---|---|---|---|
| GCT | = $07^h52^m00^s$ | LHA West | = 334° |
| GHA ♈ for $07^h50^m$ | = 4°27′ | Long. West | = 117°28′ |
| Corr. for $2^m$ | = 30′ | GHA* | = 451°28′ |
| GHA ♈ | = 4°57′ | —GHA ♈ | = 4°57′ |
| | | SHA* | = 446°31′ |
| | | | —360° |
| | | SHA* | = 86°31′ |

Enter Air Almanac
SHA* 86°31′
Dec. 35°S

Star is Kaus. Australis



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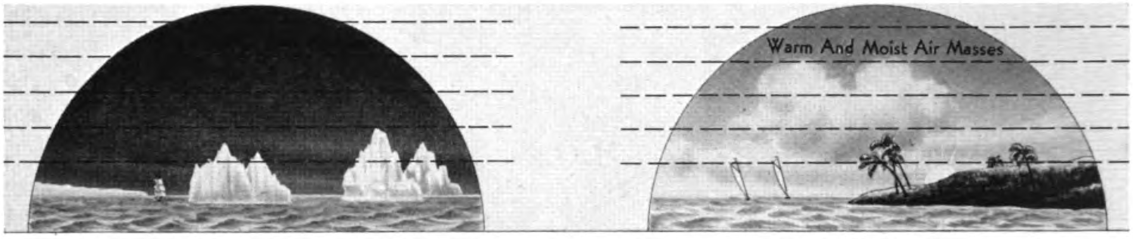


POLAR AIR MASS

TROPICAL AIR MASS

Dotted Lines Illustrate Different Levels Where Temperature, Pressure and Moisture Content Are Relatively the Same Throughout the Air Mass.

FIG. 142—CHARACTERISTICS OF AIR MASSES DERIVED FROM SOURCE REGIONS

## PRACTICAL WEATHER MAP FORECASTING

Weather map forecasting is the science of graphically recording possible weather and winds to be expected along a proposed route. This information is predetermined, primarily by reference to known observations of past weather. If the sky were continually clear, weather in itself would be relatively unimportant. But the fact that temperature and pressure changes cause rain, snow, fog, hail, or any number of various other weather phenomena makes a study of meteorology—or at least a general knowledge of its more important aspects—essential to successful flight.

This knowledge is of particular interest to the navigator, who is responsible for seeing that his aircraft reaches its destination safely. It is apparent that an aircraft, having no physical ties to the earth, is subject to every weather condition generated by the atmosphere.

A general knowledge of the fundamentals of meteorology and an understanding of the problems of the meteorologist in forecasting weather, together with the ability to converse with the meteorologist in his own terms, are important qualifications for the air navigator of today. The following is an attempt to familiarize the navigator with the more important aspects of weather analysis in general, and to acquaint him with the causes and effects of weather phenomena as they apply to him in particular.

**Air Masses**—An air mass is a large body of air approximating horizontal homogeneity. In other words, the physical characteristics are the same over a large area at different levels. These large bodies of air derive their characteristics from, and are named for, their source regions. That is, air masses originating over polar regions are inherently cold and dry. Those originating in tropical regions tend to be warm and moist (Figure 142). Tropical and polar, therefore, are the names generally applied to warm and cold air masses respectively; however, the source region does not necessarily have to be the tropical or polar region. For instance, large air masses which become stagnant over the Gulf of Mexico take on the warm, moist characteristics of the Gulf water, and in the winter the large air mass between the Cascades and the Rocky Mountain range becomes cold and dry.

The air mass, though it is stagnant long enough to take on the characteristics of its source region, does not remain stagnant, because wind changes and air pressure phenomena cause it to move across the surface of the earth. As the air mass moves it begins to take on the properties of the surface over which it passes. For example, a cold, dry air mass which lingers over a warm body of water takes on moisture and heat. As it warms and expands it is able to hold more moisture. The air mass, however, does not simply mix, but instead the cold air being heavier underruns the lighter, warmer air causing a discontinuity known as a frontal surface, which chiefly causes storms.

**Pressure Systems**—A study of the movement of air masses must take into consideration the development of high and low pressure areas. Temperature is the chief cause of changing pressure. The atmosphere contracts at low temperatures and, concentrating over a smaller area, exerts higher pressure. Conversely, high temperatures cause air to expand and the resulting distribution of its weight results in lower pressure (Figure 143).



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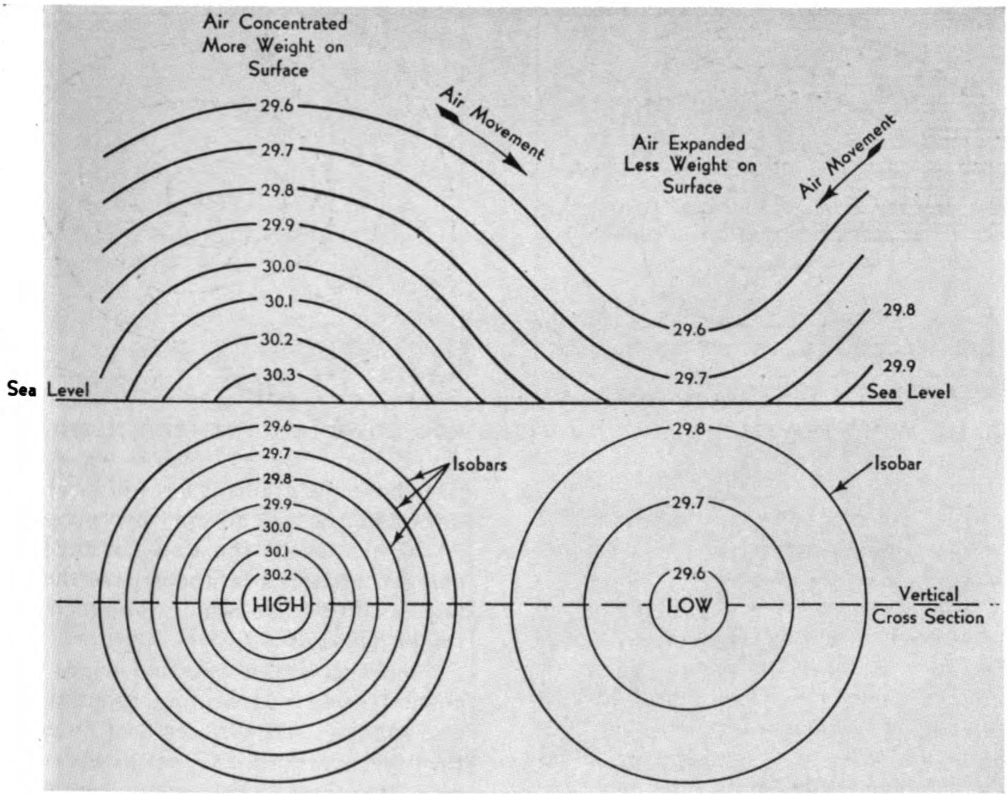


FIG. 143—PRESSURE SYSTEMS AND ISOBARS

**Isobars**—Isobars are lines connecting points of equal barometric pressure. By reference to these lines on a synoptic chart (a chart which condenses much data into one source), high and low pressure areas may be located in a manner similar to that used to show mountains and valleys on an aeronautical chart by means of contour lines (Figure 143).

**Winds**—Wind is merely the result of moving air. This movement takes place from an area of high pressure toward an area of low pressure in an attempt to equalize the total atmospheric pressure. Figure 143 shows how air moves in a manner similar to water flowing downhill. The steeper the gradient, the faster the flow. It is obvious, then, that the closer the isobars are together, the faster will be the flow of air indicated, hence the greater the wind velocity. Thus far it would seem, taking into consideration only the gradient force, that the wind would blow in a direction perpendicular to the isobars toward the low pressure area. However, a deflecting element known as *Coriolis force* must be considered. This force is a result of the rotation of the earth upon its axis, and turns all winds to the right in the Northern hemisphere and to the left in the Southern hemisphere. It then becomes apparent that, in the Northern hemisphere, winds develop a counterclockwise movement toward the center of a low or cyclonic area, and a clockwise movement outward from a high or anticyclonic area. This is illustrated in Figure 144. The same force causes the reverse situation in the Southern hemisphere. Turning to the left instead of to the right, the movement becomes clockwise in a low and counterclockwise in a high. The direction of the wind is always given in degrees, measured clockwise from true North in the direction from which the wind is blowing.

Surface winds are affected by local high and low pressure areas, while upper air winds more or less conform to the prevailing highs and lows and change with frontal systems. That is, winds in mid-latitudes become prevailing westerlies in both hemispheres where they



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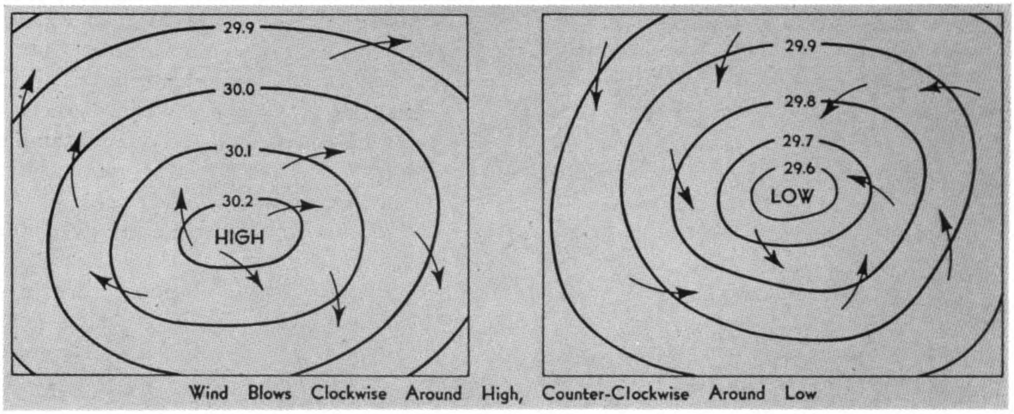


FIG. 144—WIND MOVEMENT AROUND HIGHS AND LOWS IN NORTHERN HEMISPHERE

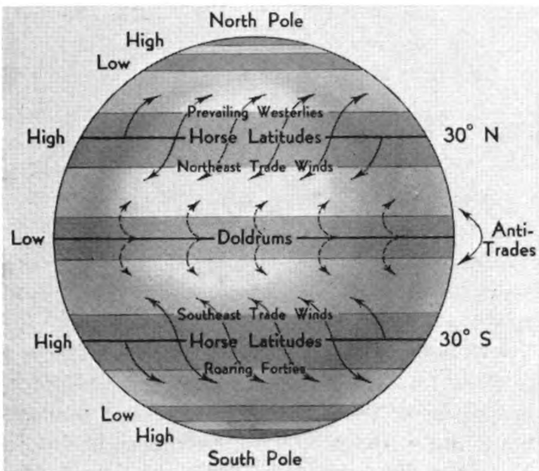


FIG. 145—EARTH'S BASIC WIND CIRCULATION

rise above the gradient force of local highs and lows and are less affected by surface friction. At higher levels, the Coriolis force predominates. Equatorial latitudes have their prevailing easterly trade winds for much the same reason (Figure 145).

Another factor affecting winds is the unequal cooling and heating properties of land and water. Land surfaces heat quickly during the daytime, resulting in sea breezes blowing in over the coast. Conversely, land areas cool faster at night, causing winds to shift and resulting in land breezes out to sea. This phenomenon becomes important when flying close to continental coastlines.

## CLOUDS

**Cloud Families**—Clouds are a visible sign of atmospheric activity, appearing as visible

| | |
|---|---|
| HIGH CLOUDS (CH) MEAN LOWER LEVEL 20,000 FEET | |
| 1. Cirrus (Ci) | Thin and Featherlike |
| 2. Cirro-cumulus (Cc) | Thin—Cotton or Flakelike |
| 3. Cirro-stratus (Cs) | Very Thin—High Sheet Cloud |
| MIDDLE CLOUDS (CM) MEAN LEVELS 6500 TO 20,000 FEET | |
| 4. Alto-cumulus (Ac) | Puffy—Sheep Back |
| 5. Alto-stratus (As) | Medium High—Uniform Sheet Cloud |
| LOW CLOUDS (CL) MEAN LEVELS CLOSE TO SURFACE TO 6500 FEET | |
| 6. Strato-cumulus (Sc) | Globular Masses or Rolls |
| 7. Stratus (St) | Low Uniform Sheet Cloud |
| 8. Nimbo-stratus (Ns) | Low Amorphous and Rainy Layer |
| VERTICAL CLOUDS (CL) MEAN LEVELS 1600 TO 20,000 FEET | |
| 9. Cumulus (Cu) | Dense—Dome-shaped and Puffy |
| 10. Cumulo-nimbus (Cb) | Towering Cauliflower—Anvil Top |

FIG. 146—CLOUD FAMILIES



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moisture condensed from warm, moist air which is cooled by expansion upon rising to higher levels. The two basic cloud types are cumuliform and stratoform, the former being developed vertically in puffy shapes, and the latter appearing as more or less flat sheet clouds. These are further broken down into four family names according to the heights at which they are found. Symbols for these clouds are shown on all weather maps.

Figure 146 shows the cloud families.

**Ceiling**—The height of the clouds above the surface of the earth is defined as ceiling.

**Sky Cover**—The amount of clouds covering the dome of the sky is shown by four symbols (Figure 147):

| Symbol | Classification | Sky Cover |
|---|---|---|
| O | Clear | Total Sky Cover less than one-tenth. |
| ◐ | Scattered | One-tenth to five-tenths covered. |
| ◑ | Broken | More than five-tenths but less than nine-tenths. |
| ⊕ | Overcast | Over nine-tenths of sky covered. |

FIG. 147—SKY COVER

**Fogs**—Practically the only difference between a fog and a cloud is the point of view of the observer; fog is nothing more than a stratus cloud on the surface of the earth. There are four principal types of fogs: advection, upslope, radiation, and frontal.

Advection fog is the result of warm moist air blowing over a cooler surface. Coastal sea fogs are an example of this type.

Up-slope fogs form when parcels of air are mechanically lifted over mountainous terrain and cooled to their dew point. These are obviously restricted to land areas.

Radiation fogs form mainly over land surfaces at night as a result of the earth's cooling. Prerequisites include a temperature inversion and winds of less than eight miles per hour. They are very low-hanging and disappear soon after the sun starts heating the earth once more in the morning.

Frontal fogs occur in frontal zones, principally warm fronts, where warm moist air contacts a body of colder air. They form similarly to the advection type, but are restricted to the smaller area at the front only.

## FRONTS

**General**—A front is simply a line of discontinuity separating two air masses of dissimilar characteristics. Warm moist air pushing up over the surface of colder air is cooled, and precipitation takes place. Heavier cold air squeezing in under warm moist air lifts it to the condensation level and again precipitation occurs. Familiarization with fronts is essential because most of the hazards of flying take place where these air masses of unlike qualities meet. Of particular interest to the pilot is the fact that approximately 90% of all icing takes place in a frontal zone.

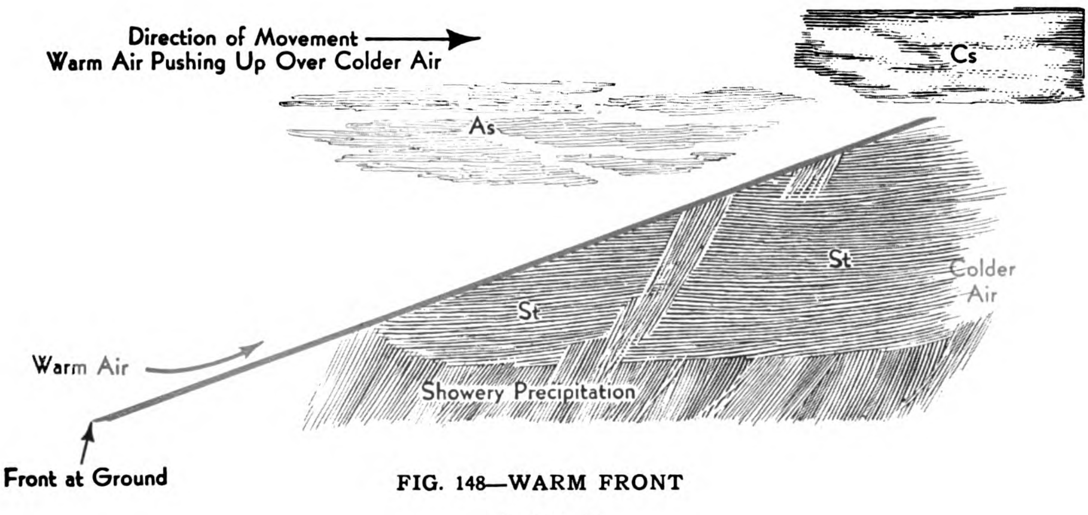


FIG. 148—WARM FRONT



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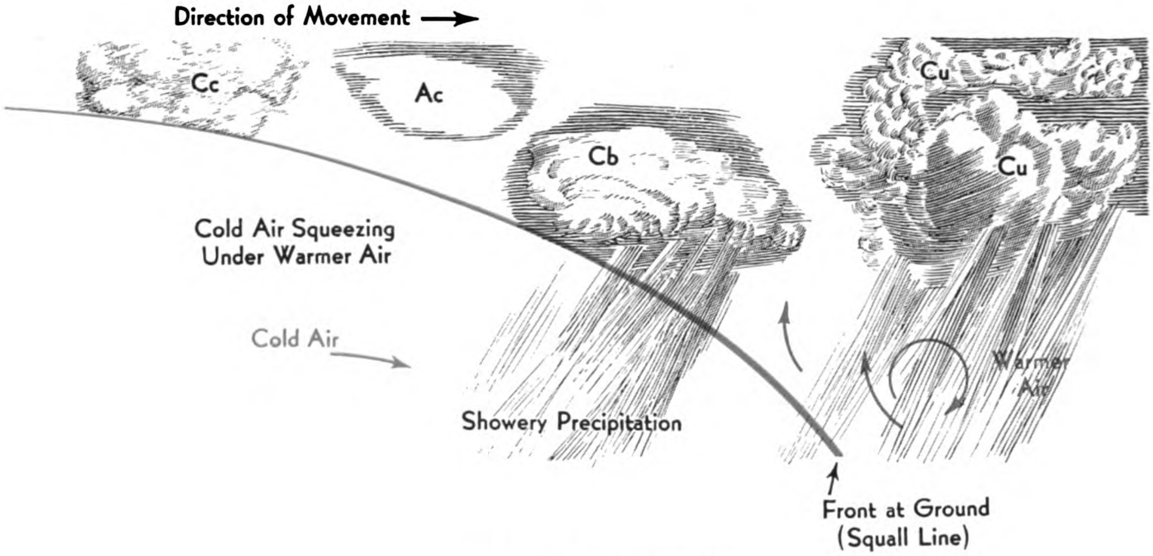


FIG. 149—COLD FRONT

The observer should remember that the fronts are shown on weather maps as a line of discontinuity at the ground. The air navigator must take into consideration the altitude of his aircraft when attempting to determine the point where he will encounter the front, in addition to the movement of the entire frontal system which occurs in an East-South-Easterly direction across the Pacific at a rate of approximately 500 miles per day. Passage of a front is recognized chiefly by a decided temperature change and wind shift; both are items of importance to be considered in air navigation. Fronts are divided into three main categories: warm, cold, and occluded.

**Warm Fronts** (Figure 148)—A warm front is indicated where warm air is replacing cold air at the ground. It has a very gentle slope upward over the colder air and is usually accompanied by stratoform clouds, lowering ceilings, and an area of steady precipitation preceding the front. The sequence of clouds observed is usually cirro-stratus, alto-stratus, and stratus. Passage of the front is indicated by an attempted clearing, a decided wind shift, humid air, and mild to moderate turbulence. The principal hazard to aircraft associated with a warm front is fog. Any icing encountered is usually of the rime variety, which is porous and can be taken care of by deicer or anti-icing equipment.

**Cold Fronts** (Figure 149)—Cold air is replacing warm air at the ground in the case of a cold front. A fast-moving cold front is accompanied by severe turbulence and line squalls which may include frontal thunder storms recognized by the familiar cumulo-nimbus clouds with their anvil tops. Precipitation is more intense but usually confined to the showery type in spotted areas under the cumulus clouds. Hail may be encountered if temperatures are low enough and high swelling cumulo-nimbus clouds are present. In many cases under these conditions, vertical currents beneath these clouds are in excess of 100 miles per hour. It is sufficient to say that they can be dangerous. Passage of the front is indicated by a decided wind shift and drop in temperature followed by clear, cold, good flying weather. Cumuliform clouds follow after the front. The slope is steeper than the warm front.

The principal hazard of the cold front is icing, but also may include severe vertical currents and probable hail showers. Icing is mostly of the clear type which spreads quickly and destroys the airfoil. Vertical currents support larger droplets of water which spread before freezing.

**Occluded Fronts**—In an occluded front warm air is squeezed off the ground entirely and replaced by colder air. By reference to



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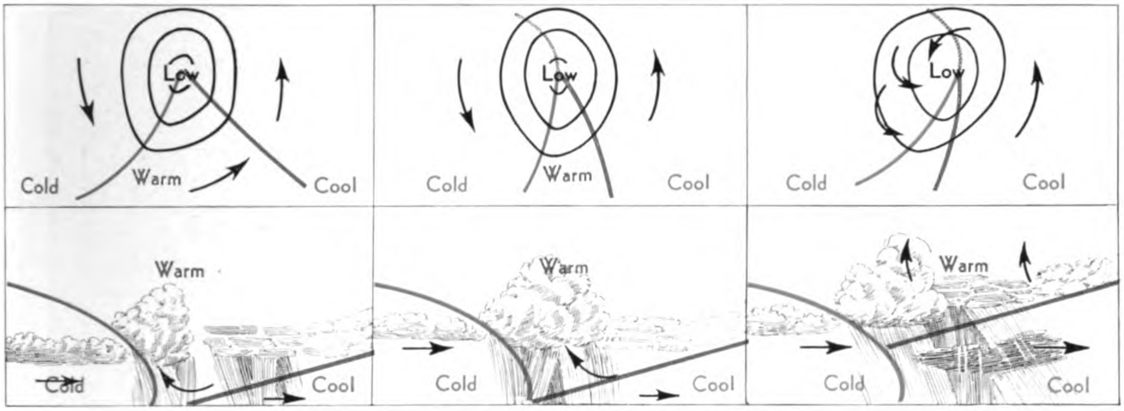


Occluded Front
Warm Front
Cold Front

FIG. 150—DEVELOPMENT OF OCCLUDED FRONT

Figure 150 it will be seen that an occluded front is actually the breaking up of a low pressure area, and passage directly through the occluded part will be accompanied by a drop in temperature and very changeable winds. Passage to the south will encounter successive warm and cold fronts according to the direction of flight. Figure 150 shows both top and side view drawings of an occlusion in process.

## SUMMARY

Figure 151 represents a typical weather map. The summary below will follow through a flight, and indicate how you, as the navigator, would analyze this information for flight purposes.

First of all, notice the GCT for which the map was drawn, which is important in that the fronts to be crossed on your course are located for $18^h00^m$ GCT only and will move easterly at approximately 21 miles per hour as we progress. It is apparent that temperatures will gradually rise as we leave San Francisco, and that we will be aided by moderately increasing tail winds.

We may expect to encounter the warm front indicated by the heavy red line considerably sooner than indicated, due to the fact that, in addition to the front having moved toward us, its gentle forward slope will cause us to encounter it even sooner at our flight altitude. The definite wind shift from East to Southwest will be accompanied by a slow increase in temperature, weather clearing, and smooth air after passage through the front. Low stratus clouds will probably be observed preceding the front with an area of continuous precipitation underneath.

A second wind shift may occur with probable head winds as the heavy blue line (cold front) approaches. It will be noted that at $18^h00^m$ GCT, this front is at Honolulu, but will have passed Honolulu before your arrival. Assuming we have a fast plane, we may still pass South of the approaching line squalls which would be visible ahead as a black wall of clouds in the daytime, or evident by the blotting out of low stars at night in the general direction. In any event, we should be prepared to alter course to the left to avoid considerable turbulence and rough weather. This is based on the assumption that the line of discontinuity in question separates air masses of decidedly opposite characteristics. We would be advised of this previous to take-off by the meteorologist in charge.

Assuming that we pass South of the approaching cold front, we may still expect head winds gradually increasing in velocity. This is made evident by the fact that the isobars are closer together, and by the presence of a low pressure area moving in from the Northwest.

The approaching cold front will definitely cross our path and will indicate its passage by a temperature drop, squally weather, and the presence of cumulus type clouds. The intensity of its vertical currents and turbulence may be



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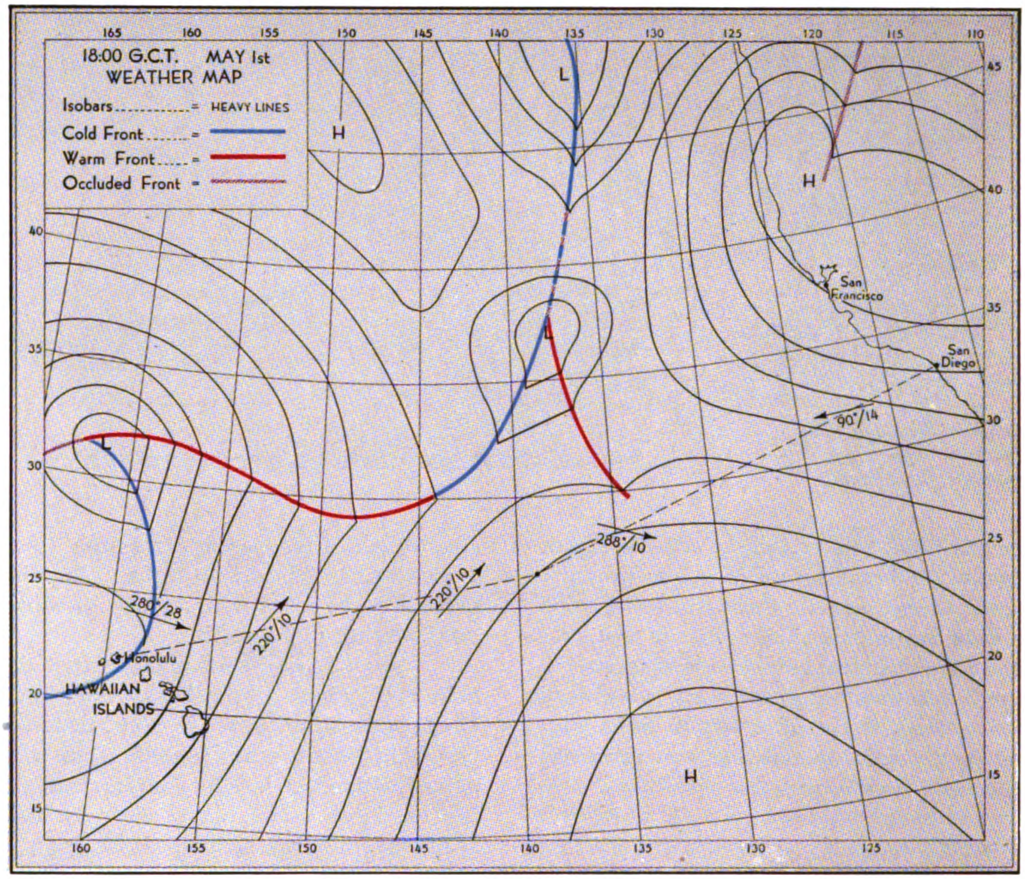


FIG. 151—TYPICAL WEATHER MAP

judged by the vertical swelling of its cloud systems.

The knowledge obtained from the meteorologist before the take-off may be augmented by a radio weather report from Honolulu as to the frontal conditions which we will encounter.

Another wind shift from Southwest to Northwest may be expected after passage of the front. Head winds are still prevailing but the shift may counteract the drift applied on our present heading. A celestial fix at this time should show us any drift tendency, and our destination should be in sight shortly thereafter.

**Note:** No attempt is made in the foregoing to go deeply into meteorology as a science with its accompanying lapse rates, pressure tendencies, and various weather phenomena. The effort has been directed entirely toward acquainting the air navigator with the basic principles as they apply to the safe flight of his aircraft. Perhaps the air navigator of tomorrow will himself be a competent meteorologist. Until then, he can learn a great deal through intelligent conversation with the weather forecaster if he has been trained to know *what the forecaster is talking about* in addition to knowing *what to look for* and the probable results.



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**PROBLEM WORK NO. 30**

**STAR IDENTIFICATION BY H. O. 214**

(Identify stars by H. O. 214 method.)

| No. | DATE | GCT | DR POSITION | | Ho | AZIMUTH | STAR |
|---|---|---|---|---|---|---|---|
| | | | Lat. | Long. | | | |
| 1 | 5- 5-43 | 13:27:00 | 37°50′N | 121°01′E | 19°58′ | N 55°E | |
| 2 | 5- 1-43 | 13:14:00 | 39°24′S | 110°31′E | 37°12′ | S 80°W | |
| 3 | 5-10-43 | 11:24:00 | 38°15′N | 146°14′E | 38°15′ | N160°E | |
| 4 | 5- 5-43 | 19:43:00 | 36°14′S | 89°45′E | 25°00′ | S 120°E | |
| 5 | 5-20-43 | 13:40:00 | 32°40′N | 123°14′E | 38°02′ | N100°W | |
| 6 | 5- 1-43 | 12:04:00 | 38°42′S | 173°13′W | 36°14′ | S 25°W | |
| 7 | 5-25-43 | 00:49:00 | 34°17′N | 64°50′W | 53°08′ | N 90°E | |
| 8 | 5-30-43 | 02:43:00 | 35°10′S | 84°30′W | 51°10′ | S 90°E | |
| 9 | 5-20-43 | 08:32:00 | 30°10′S | 135°11′W | 44°04′ | S 80°E | |
| 10 | 5-15-43 | 19:24:00 | 34°48′S | 132°12′E | 51°34′ | S 110°W | |
| 11 | 5-25-43 | 20:48:00 | 33°21′S | 56°46′E | 44°38′ | S 165°E | |
| 12 | 5-30-43 | 07:52:00 | 32°16′S | 117°28′W | 67°26′ | S 75°E | |
| 13 | 5-25-43 | 11:36:00 | 30°03′S | 137°17′E | 18°08′ | S 40°W | |
| 14 | 5-10-43 | 10:30:00 | 33°45′N | 179°46′W | 59°32′ | N120°W | |
| 15 | 5- 1-43 | 02:44:00 | 38°30′N | 43°28′W | 66°40′ | N 35°W | |
| 16 | 5-15-43 | 19:33:00 | 31°38′N | 32°32′E | 24°26′ | N140°E | |
| 17 | 5-10-43 | 02:17:00 | 39°18′S | 28°04′W | 67°22′ | S 85°E | |
| 18 | 5-20-43 | 14:32:00 | 37°10′N | 122°44′E | 23°46′ | N 50°E | |
| 19 | 5- 5-43 | 18:42:00 | 31°26′N | 170°23′W | 60°04′ | N 85°E | |
| 20 | 5-15-43 | 18:22:00 | 36°20′N | 146°12′W | 34°52′ | N170°E | |



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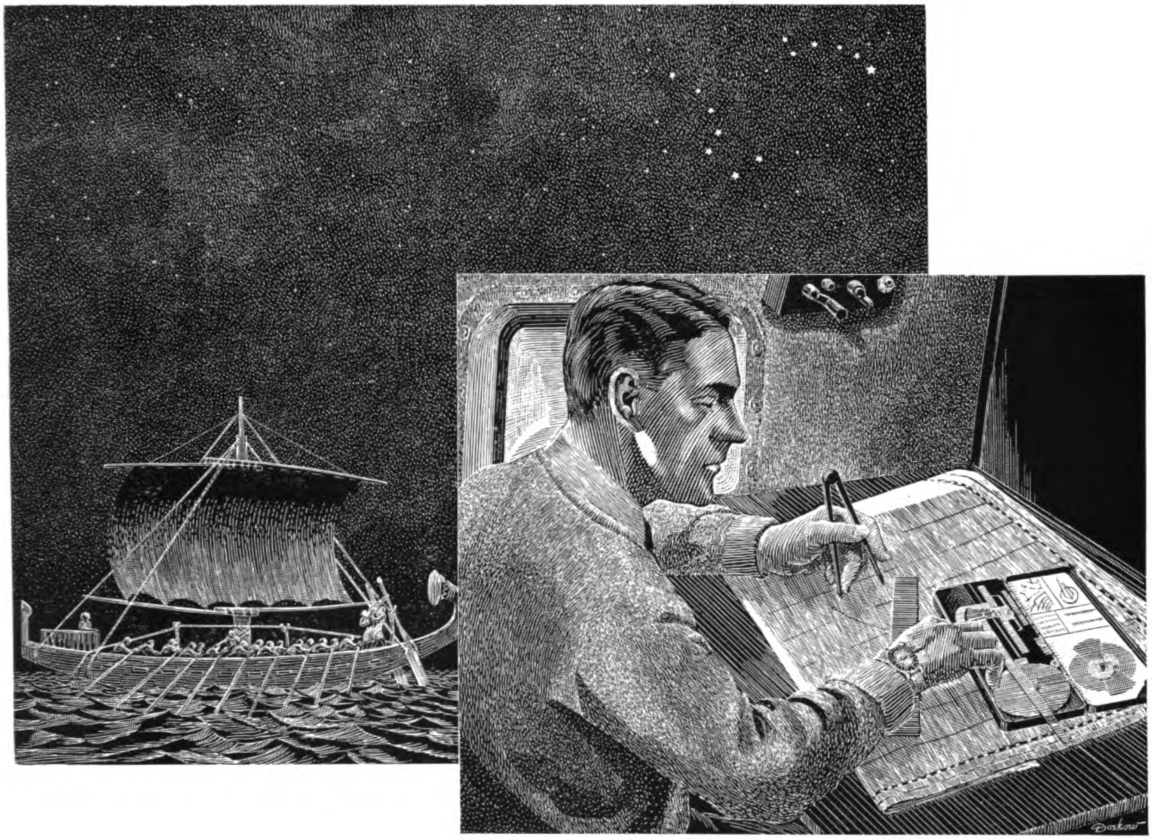

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# SPECIAL PROCEDURES

THE navigator who understands and applies all available navigation procedures, keeps a constant check on his aircraft's track and carefully analyzes all position data for possible errors, will be able to report quickly, and within close limits, the position of his aircraft at any time. Furthermore, he seldom will *feel* in doubt as to his location.

However, certain factors over which he has no control—such as weather, or fatigue—may cause him temporary uncertainty. At such times, position-finding data appears conflicting and unreliable, and it is then that the navigator must guard against the natural tendency to become excited and confused. Several rules apply under such circumstances:

1. *Remain calm.* A cool mind functions much better in an emergency than one which tries to make decisions under emotional tension.
2. *Act intelligently.* Use common sense.
3. *Continue searching for information.* The best plan, of course, is to try to obtain a celes-



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tial fix. If this is not possible, perhaps there are gaps in the overcast which will at least permit securing of a single L.O.P., which can be used for a track or ground speed check. Also, it may be possible to climb above the overcast.

At the same time, the navigator should continue trying for radio bearings which, either alone or combined with celestial lines of position, will enable him to establish his location.

4. *Recheck all work.* Correction of a careless mistake may enable you to establish your position.

5. *Most important of all—do not alter aircraft's heading* unless the decision to do so is based upon definite information.

## FIXED SQUARE SEARCH

In the event the E.T.A. has elapsed without the destination having been sighted, the best procedure is to continue on the same heading until certain the objective has been passed. The navigator should keep trying to get celestial lines of position or radio bearings which will give him definite information as to the aircraft's position. If such information cannot be obtained and the navigator is entirely dependent upon DR, direction of flight should be continued for a period of from 20 to 30 minutes, depending upon the accuracy with which ground speed was known when computing the E.T.A., and also upon the amount of fuel remaining. If the destination has not been sighted by then, nor any new position data obtained, a fixed square search procedure may be instituted. This is a method by which an aircraft can systematically search a fairly large area to locate a small object, such as an island, a disabled ship or a life raft. It is called a "fixed" square search, because it presumes that the object being sought is stationary. Before beginning the search it is necessary to determine the visibility (or the distance, in nautical miles, the observer can see in any direction). This distance is the *visibility factor* (V), and is based on the size of the object being sought, altitude of the aircraft and, principally, the

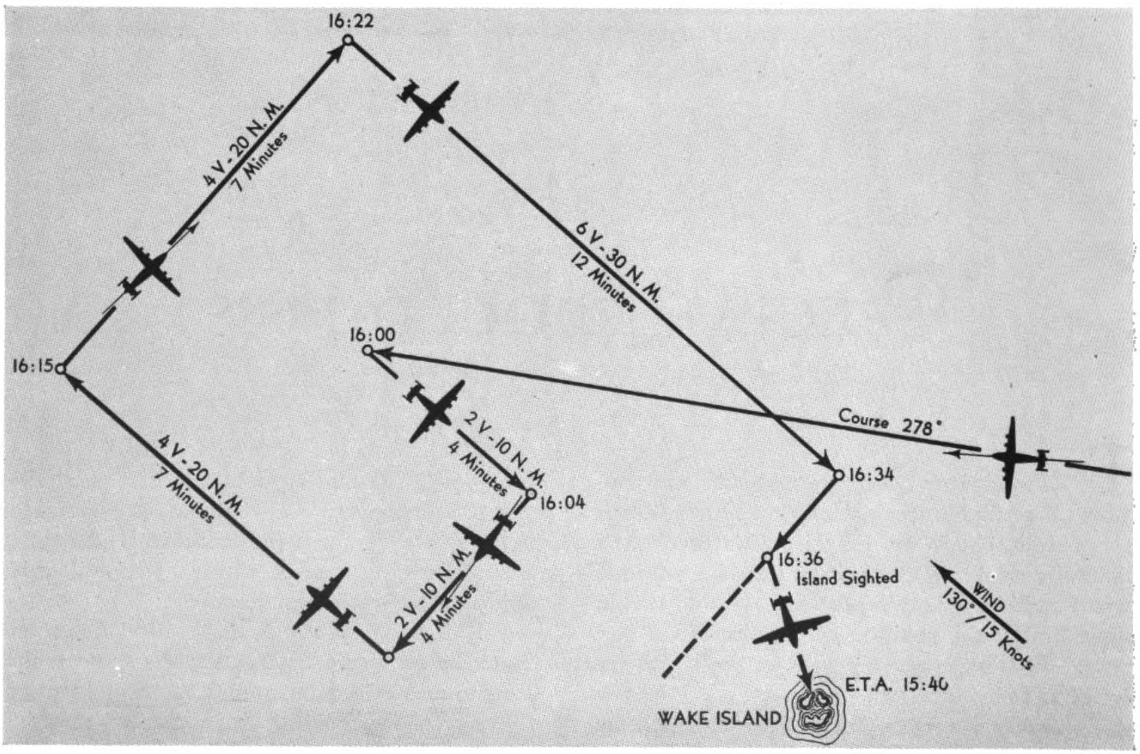


FIG. 152—SQUARE SEARCH PROCEDURE



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visibility of the atmosphere. As visibility often is difficult to estimate, it is wise to be conservative in choosing a visibility factor. The determination of this factor, and the application of the square search procedure is illustrated by the following example.

*Example* (Figure 152):

The navigator of an aircraft having exceeded his E.T.A. (15:40 GCT) by 20 minutes without sighting his objective (Wake Island), is authorized by the captain to institute a fixed square search procedure. Accordingly, at 16:00 GCT he advises the captain to assume a heading of 130° true in order to fly directly into the wind for the first leg. This upwind heading is flown first, both because it requires no drift calculation and because it reduces the ground speed to a minimum, thus affording more time in which to compute headings for the other legs. The T.A.S. is 165 knots; the wind—determined as carefully as possible by estimate, forecast, or double drift—is 130°/15 knots. The atmospheric visibility appears to be about eight miles, but to be safe the navigator decides to use a visibility factor of five miles.

The upwind heading is held for a distance equal to 2V (10 miles). And since the aircraft is flying upwind, its ground speed is equal to T.A.S. less the velocity of the wind, or 150 knots. Therefore, it requires 4 minutes to complete the first leg. When the first leg has been completed (16:04), the pilot turns to the right, putting the aircraft on a true heading of 215°. This heading was worked out by the navigator during the first leg, and includes proper drift allowance. This second heading enables the aircraft to make good a track 90° from the first leg.

**Note:** Instead of turning *right,* as cited in this example, the pilot might have turned *left* to assume a course 90° to the *left* of the original track. Direction of turn is dictated by circumstances under which the search procedure is employed.

This second heading is, in turn, held until a distance equal to 2V (10 miles) has been covered, which requires 4 minutes. When the second leg has been completed (16:08 GCT) the pilot again turns to the right and flies directly downwind (true heading 310°) for the third leg, a distance equal to 4V (20 miles). At 16:15 GCT, heading is again altered to 045° in order to make good a track 90° from that flown on the third leg, and a distance of 4V (20 miles) is flown on this heading.

Since Wake Island still is not in sight on completion of the fourth leg (16:22 GCT), the navigator prepares to repeat the entire procedure, again increasing the distance to be flown by 2V for each succeeding two legs. Accordingly, at 16:22 GCT a right turn is made to begin the fifth leg, which, like the first leg, is directly upwind. This upwind heading is held for a distance equal to 6V (30 miles). Wake Island is not sighted on the fifth leg, so at 16:34 GCT a right turn is made for the sixth leg. After flying on this leg for two minutes, the island is sighted, bearing 160° true and seven miles distant. On checking his search plan, the navigator finds that Wake Island actually was 26 miles distant, bearing 127° true from the aircraft when the search was started.

## RUNNING DOWN A SUN LINE

Running down a sun line is a procedure used by the navigator to reach a difficult objective, such as a small island, when only the sun is available for observation.

For instance, assume that an aircraft is making a daylight flight from Honolulu to Canton Island. During the day, the navigator has been estimating his position solely by sun position lines and drift meter readings. The sun lines have given him a fair estimate of the aircraft's position. However, several hours from Canton Island, he turns on the radio direction finder in order to make sure of his approach, and finds the radio isn't working.

Canton Island is a very small coral atoll, and the navigator knows that if he were only a few miles off course he could easily pass Canton by without seeing it. He therefore recommends to the captain that it would be advisable to run down a sun line.

**The procedure** is as follows (Figure 153):

Given: course 209°—G.S. 180 knots.

a. About one hour from Canton Island the navigator observes the sun and obtains the 03:10 position line. From previous position lines and drift meter readings he indicates the



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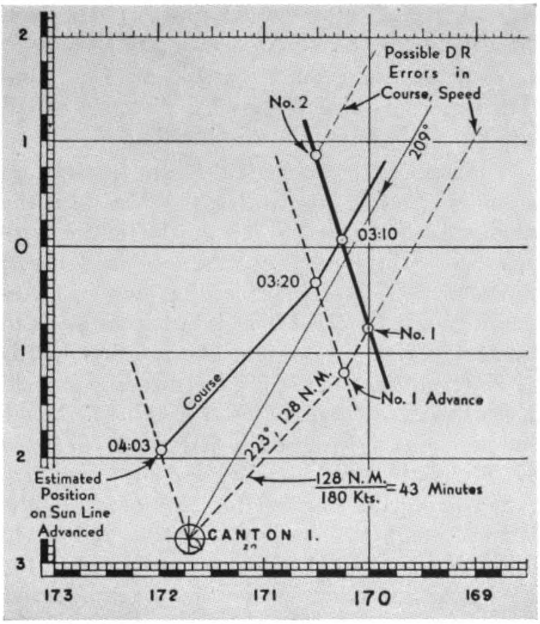


FIG. 153

most probable position on the sun line with a circle.

b. He then estimates possible errors in ground speed and course, and finds positions No. 1 and No. 2, which represent possible position limits on the sun line.

c. 03.20—Since it took ten minutes to calculate and plot the sun line, he advances position No. 1 ten minutes of ground speed and measures the course to Canton as 223°, distance away 128 NM.

d. Altering compass heading to fly 223° true, he then knows the aircraft will be definitely to one side of Canton, and should be somewhere on the position line advanced through Canton Island at 04:03.

e. To check, he again observes the sun and plots another position line at 03:40. Advancing this line through Canton Island, he determines the aircraft will be somewhere on the advanced line at 04:00 (Figure 154).

f. Therefore, at 04.00 he once more alters compass heading to fly 168° true which would run down the sun line, and thus fly over Canton Island.

g. Until Canton Island is sighted, however, he continues to plot sun lines at ten-minute intervals to make certain his course will pass over the island.

## LATITUDE BY MERIDIAN ALTITUDE

To take a meridian altitude sight means to measure the altitude of a celestial body when it is on the observer's meridian. This procedure is employed to determine the observer's latitude, and it is one of the simplest problems in celestial navigation. Its solution is derived from the fact that when a body is on the observer's meridian, its local hour angle is zero, hence the astronomical triangle is reduced to a straight line (Figure 155).

**Procedure** — The procedure necessary to determine latitude by meridian altitude is as follows:

a. Observe altitude of celestial body.

b. Find zenith distance (Zd) by subtracting true altitude ($H_O$) from 90°.

$$90° - H_O = Zd$$

c. Determine bearing of observer's zenith from the celestial body (North or South) and name zenith distance accordingly. Thus, in example No. 1 (Figure 155), the zenith is North of the celestial body. Zenith distance, therefore, takes the name *North.* In example No. 2 (Figure 155), the zenith is South of the celestial body. Zenith distance, therefore, takes the name *South.*

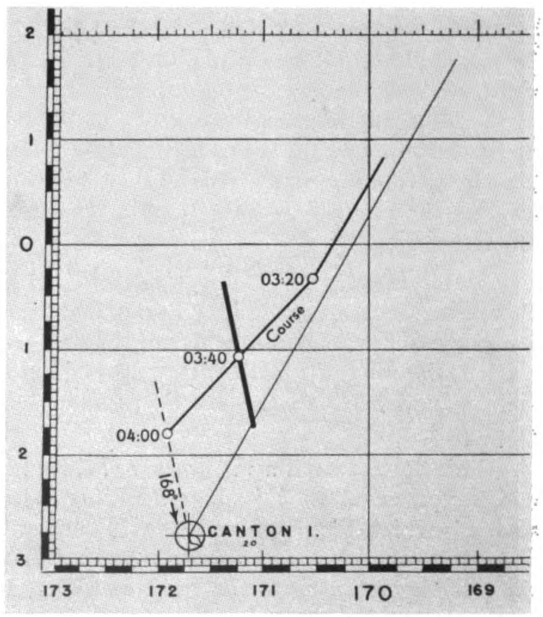


FIG. 154



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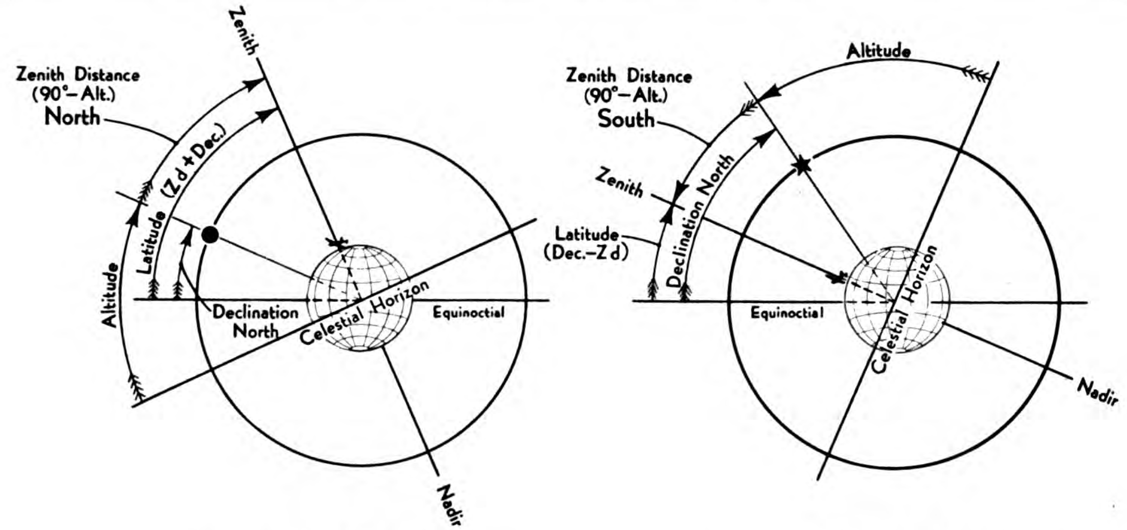


Example No. 1
Observer's Zenith North of Celestial Body

Example No. 2
Observer's Zenith South of Celestial Body

**FIG. 155—LATITUDE BY MERIDIAN ALTITUDE**

d. Combine zenith distance and declination to obtain observer's latitude. If values have same name, add them together and give the resulting latitude their common name. If values have contrary names, subtract smaller from larger to obtain their difference which will take the name of the *larger* value and will, again, represent the observer's latitude.

$$\text{Zd} \sim \text{dec.} = \text{Latitude}$$

*Example* No. 1

Observer's Zenith North of celestial body

| | |
|---|---|
| $H_s$ Sun | = 55° 00′ |
| Refraction | = 0′ |
| $H_o$ | = 55° 00′ |
| | from 90° 00′ |
| ZD | = 35° 00′ N |
| Declination | = 12° 00′ N |
| Latitude | = 47° 00′ N |

*Example* No. 2

Observer's Zenith South of celestial body

| | |
|---|---|
| $H_s$ Star | = 60° 00′ |
| Refraction | = 0′ |
| $H_o$ | = 60° 00′ |
| | from 90° 00′ |
| ZD | = 30° 00′ S |
| Declination | = 43° 00′ N |
| Latitude | = 13° 00′ N |

## FINDING TIME OF MERIDIAN TRANSIT

When the GHA of a celestial body is the same as the observer's longitude, the LHA is zero. This instant is called the *time of meridian transit*.

As has been previously stated, longitude may be defined as the angle, measured at the *terrestrial* poles, between the Greenwich meridian and the meridian of an observer. Similarly, GHA may be defined as the angle, measured at the *celestial* poles, between the Greenwich (celestial) meridian and the celestial meridian (hour circle) of a celestial body. It is apparent, therefore, that longitude and GHA correspond exactly, the only difference being that GHA is measured to the West through 360°, whereas longitude is measured East *or* West through 180°.

**Graphic Method** — The time of meridian transit may be found graphically by advancing the DR position of the observer along the course until his DR longitude is equal to the GHA of the body (found in the Air Almanac) for the same instant of time. This procedure is illustrated in the following example:

*Example* (Figure 156):

On January 1, at $17^h00^m$ GCT in longitude 100° 10′ West, the navigator desires to precompute the time of meridian transit of the sun.



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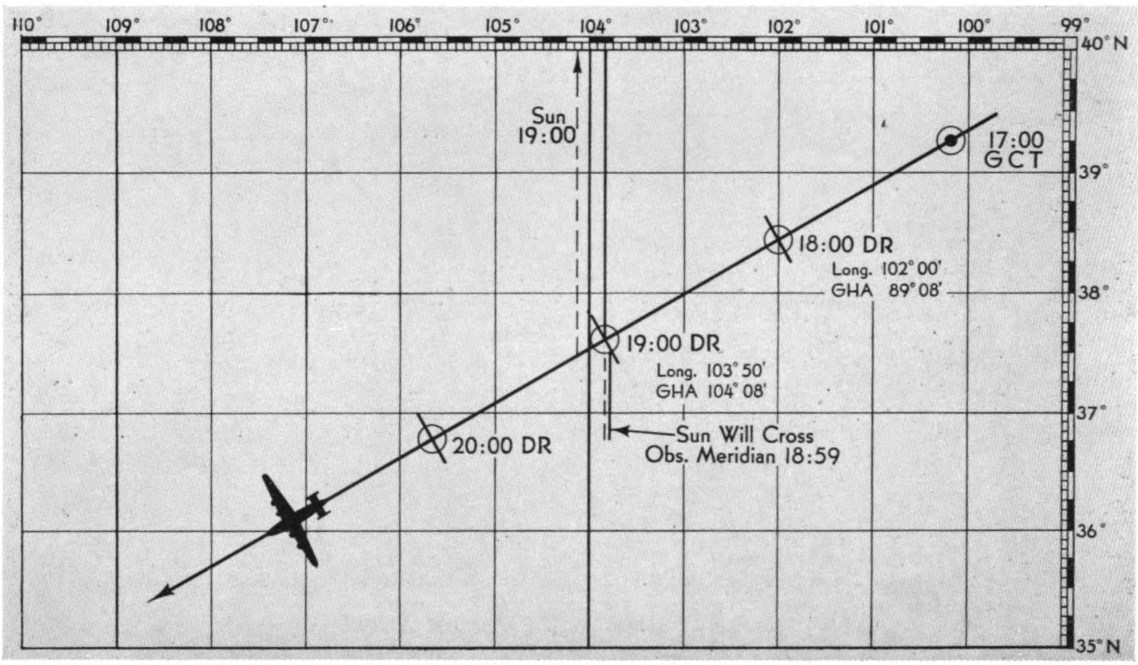


**FIG. 156—FINDING TIME OF MERIDIAN TRANSIT**

His course is 240° true and ground speed 102 knots.

Referring to the Air Almanac, he finds the GHA to be 89°08′ for $18^h00^m$ GCT. His DR longitude, however, he computes 102°00′, hence the sun will still not have overtaken him by this time. Accordingly, the navigator again computes his DR longitude, this time for $19^h00^m$ GCT, and finds it to be 103°50′. He then notes the tabulated GHA as 104°08′, hence the sun will by this time ($19^h00^m$ GCT) be 18′ past his meridian, or approximately one minute of time.

**Note:** A celestial body advances in longitude to the West

15° in one hour
1° in four minutes
¼°, or 15′ in one minute

Therefore, he concludes that the time of meridian transit will be very close to $18^h59^m$ GCT.

**Rate of Closure Method**—The time of meridian transit also may be worked as a *rate of closure* problem (rate at which celestial body is overtaking the aircraft). The procedure is as follows:

a. On an even hour before meridian transit, step off *one hour of ground speed along the course.*

b. Next, measure the aircraft's rate of departure, that is, the number of degrees and minutes of longitude which the aircraft crosses in one hour.

c. Since a celestial body travels westward, traversing longitude at the rate of 15° per hour, find the rate of closure (R of C), or rate at which the sun is overtaking the aircraft, by subtracting the aircraft's rate of departure from 15°.

d. The LHA of the celestial body at the time of departure is the distance in degrees and minutes of arc which the body must close in order to overtake the aircraft. Therefore,

$$\frac{\text{LHA}}{\text{R of C}} + \text{GCT departure} = \text{time of meridian transit.}$$

*Example:*

Using the same data as in the previous example (Figure 156), the navigator determines the aircraft's rate of departure to be 1°53′ of longitude per hour. Therefore, 15° less 1°53′ = 13°07′ R of C. (Plane flying away from sun causes sun to close at a rate less than 15° per hour).



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The navigator then finds the interval of closure (LHA at $17^h00^m$ GCT) as follows:

$$\begin{array}{lrl} \text{GCT } 17^h00^m & \text{GHA} = & 74°09'\text{W} \\ & \text{Longitude} = & \underline{100°10'\text{W}} \\ & \text{LHA} = & 25°01' \end{array}$$

Hence,

$$\frac{25°01'}{13°07'} = \frac{25.01°}{13.11°} = 1.91^h = 1^h56^m$$

or, $17^h00^m + 1^h56^m = 18^h56^m$ time of meridian transit.



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**PROBLEM WORK NO. 31**

**LATITUDE BY MERIDIAN ALTITUDE**

(Find latitude by meridian altitude method.)

| No. | CELESTIAL BODY | DATE | MTr (GCT) | $H_o$ | BEARING | LATITUDE |
|---|---|---|---|---|---|---|
| 1 | SUN | 5- 1-43 | 01:50 | 78°48′ | S | |
| 2 | SUN | 5-15-43 | 04:32 | 74°31′ | N | |
| 3 | SUN | 5-10-43 | 19:45 | 61°36′ | S | |
| 4 | SUN | 5-20-43 | 14:21 | 56°47′ | N | |
| 5 | SUN | 5- 5-43 | 22:00 | 49°48′ | N | |
| 6 | JUPITER | 5- 5-43 | 02:40 | 68°31′ | S | |
| 7 | VEGA | 5-10-43 | 11:00 | 81°09′ | N | |
| 8 | MOON | 5-20-43 | 08:14 | 41°01′ | S | |
| 9 | ARCTURUS | 5- 5-43 | 07:11 | 65°29′ | N | |
| 10 | ANTARES | 5-15-43 | 08:50 | 28°17′ | S | |
| 11 | MOON | 5-15-43 | 04:15 | 62°07′ | S | |
| 12 | SPICA | 5- 5-43 | 05:45 | 55°29′ | S | |
| 13 | REGULUS | 5- 1-43 | 03:45 | 79°26′ | S | |
| 14 | ALTAIR | 5-20-43 | 10:31 | 66°00′ | S | |
| 15 | ALKAID | 5-15-43 | 07:24 | 69°43′ | N | |
| 16 | NUNKI | 5- 1-43 | 15:14 | 76°13′ | S | |
| 17 | MIZAR | 5-20-43 | 07:58 | 76°38′ | N | |
| 18 | DENEBOLA | 5-10-43 | 05:00 | 48°47′ | N | |
| 19 | RASALAGUE | 5-15-43 | 12:13 | 71°11′ | N | |
| 20 | ALPHECCA | 5- 5-43 | 09:30 | 62°47′ | N | |



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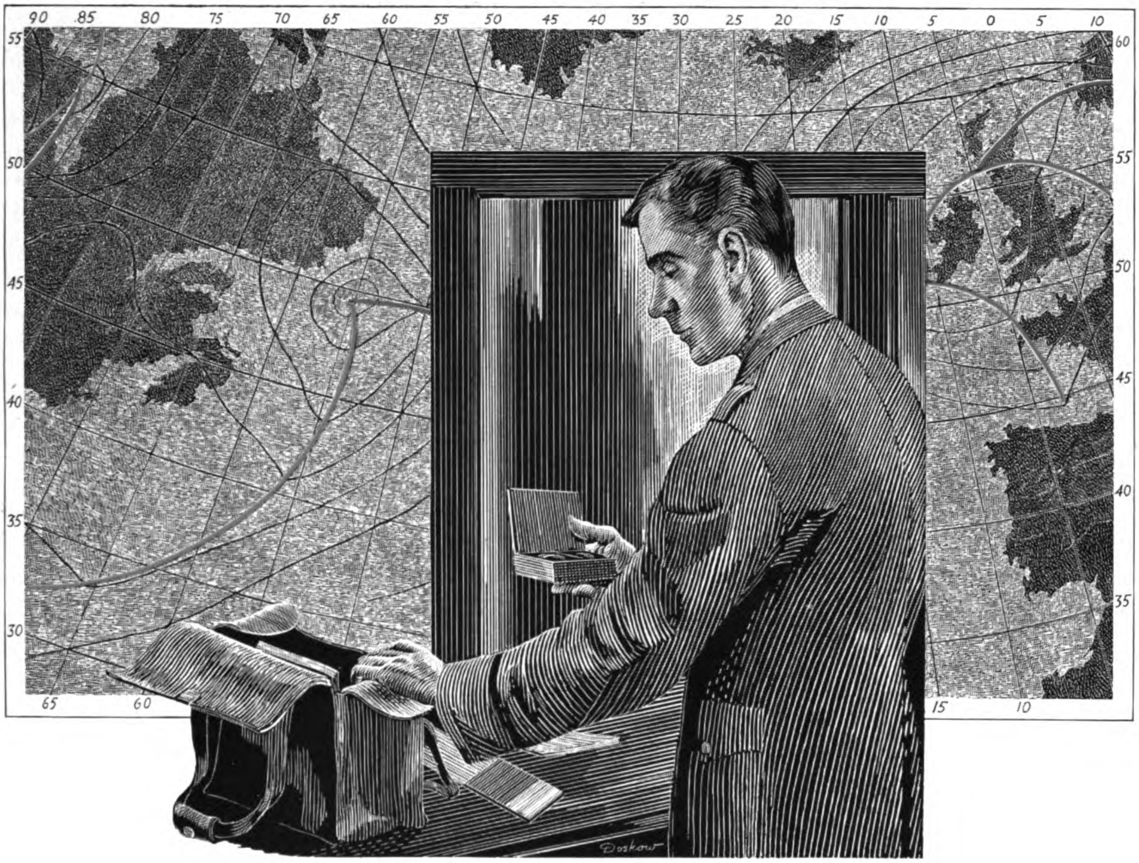


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# YOU NAVIGATE TO HONOLULU

THE following notes, experiences and flight data are based upon several actual trips made by the writer. Engine-performance curves, graphs and other factors have been altered, and essential data has been recomputed and brought up to date.

Regardless of these changes, the conditions of flight, information cited and general procedure followed are essentially the same as will apply to any long-range ocean flight and may, therefore, be considered accurate examples.

It is hoped the following description of an actual flight will furnish a more workable concept of the practical application of aerial navigation principles and methods described in earlier chapters.

**THE FLIGHT**

A phone call from the dispatch office on a May afternoon advises that you will be the navigator on a PBY scheduled for delivery to Honolulu the next day.

Next morning you are up early gathering your gear. By nine o'clock you are busy in the Airway's Navigation Office, checking over all equipment needed for the flight. You have, of course, kept it constantly ready, stowed in a



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sturdy briefcase for compact handling, but you know it always pays to make a final check. You remember well the navigator who failed to take along a current Air Almanac. Two hundred miles at sea he discovered, much to his discomfort, that the date of his Almanac had expired. Fortunately, another aircraft was nearby, on the same flight, and so by means of inter-plane radio communication, the navigator of the other aircraft dictated enough data from a current Almanac to enable him to compute celestial fixes and so continue enroute.

**Equipment Check**—You check your equipment to make certain the following items are included:

2 *Air chronometers* (very accurate watches).

1 *Aircraft octant* (including spare batteries and bulbs).

1 *Air Almanac* (correct date).

1 *Set H.O. 214 tables* (one volume for each 10° of latitude to be flown).

1 *Weems plotter* (for drawing courses and lines of position).

1 *Pair 6" dividers.*

6 *Pencils* (sharpened).

1 *Scratch pad.*

1 *Notebook* (for recording celestial sights and observations).

1 *Flashlight.*

1 *Roll of masking tape* (to hold charts down).

1 *Operations Manual* (containing the graphs and engineering data concerning engine performance and fuel consumption, and navigation aids such as sunrise and sunset tables, courses and distances*, radio aids*, radio station frequencies and identification signals*, schedule of time ticks, radio weather codes* and other essential information).

1 *Flight Manual** (containing all detailed information needed regarding check points such as islands and reefs, landing areas, air bases and other facilities along the intended or alternate routes).

1 *Set of charts* (including plotting and detail charts of all islands and landfalls along the proposed route, including possible alternates).

*These items are restricted during war, and can be obtained by the captain from Army or Navy officials only, immediately prior to departure.

**Note:** A plotting chart is most practical when its scale is small (¾ inch to 1 inch equal to 1° of longitude at the equator), because this small scale permits plotting the course for an average point-to-point flight (usually not more than 2000 miles), whereas a larger scale would necessitate changing charts. Furthermore, a small scale chart provides a clearer picture of the aircraft's track, ground speed and drift, and fixes plotted are accurate within a few miles—a negligible error in long-range flying.

**Chronometer Check**—Before placing the equipment aboard your aircraft, you first wind your chronometers and set them to correct Greenwich civil time (GCT). They are set to coincide with the master watch, kept in the navigation office, and as an additional check, as soon as possible after take-off, the radio operator will pick up a time tick so you may make absolutely certain your watches are set correctly. This is very important, as four seconds of chronometer error will result in an error of one minute of longitude (one mile at the equator).

Later in the morning you board the PBY and arrange your equipment for the flight. With masking tape, you fasten the chart you are going to use to the navigator's table. The rest of the charts you stow in a drawer, and the navigation books are put in handy places for use when needed. You then set the aircraft's watches to GCT and altimeters to zero.

**Pre-forecast Check**—The aircraft being delivered is a Consolidated Vultee Catalina type flying boat. Take-off has been scheduled for late in the afternoon in order to arrive in Honolulu sometime after sunrise tomorrow. You are not yet certain that the flight will be made today because if the weather forecast is not favorable, the flight will have to be cancelled out. Therefore, you obtain a preliminary forecast which gives you the weather and anticipated flying time, both of which look promising. So you prepare for pre-flight check.

The forecast, to be described in more detail later on, is the weather report obtained from the meteorologist (Weather Bureau in peacetime and the Army or Navy department during war). The forecast includes predicted



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weather, winds, clouds and fronts along the proposed route. Applying the force and direction of the wind to the true air speed of the aircraft, an estimate is then made of the average ground speed, and total number of flying hours. If head winds were predicted of such force as to result in the estimated total flying time being very nearly equal to the aircraft's total available fuel hours, the flight would be cancelled out, pending more favorable winds. For a Catalina, 18 to 20 hours is considered a good forecast; over 20 hours, a long forecast.

**Pre-flight Check**— By 11:00 A. M. the crew is ready to take your Catalina for its final check flight. You still won't leave if it isn't in perfect flying condition. It has had 12 hours of shakedown (flight test) and should be in good shape. However, this is your last opportunity to uncover faults, and if any remain, to have them corrected before departure.

With the crew on board, the captain takes the ship off the water and climbs to 5,000 feet where he levels off. Captain and co-pilot then conduct a series of tests to see if any faults can be shaken out—checking flying performance on first one engine and then the other, with both engines set at various manifold pressures (M.P.) and revolutions per minute (r.p.m.). Magnetos, de-icers, propeller-feathering mechanism and other devices are tested. It looks as though you have a "good airplane," as everything is running smoothly. These final shakedowns are important, as minor flaws revealed in these flights might develop into major failures in long-range flying, resulting in possible disaster for ship and crew.

**Radio Compass Check in Flight**— When the captain is satisfied that the aircraft is in good operating condition, you then check the radio direction finder loop for calibration error. This is not difficult when relative bearings (R.B.) are computed as outlined in the following procedure.

Fulfilling one of your duties as a navigator you select a small landmark—the South tip of South Coronado Island—and measure the correct magnetic heading between it and radio station KFSD, San Diego. Next, the magnetic headings to fly are computed, as well as the correct relative bearings for each 30° interval

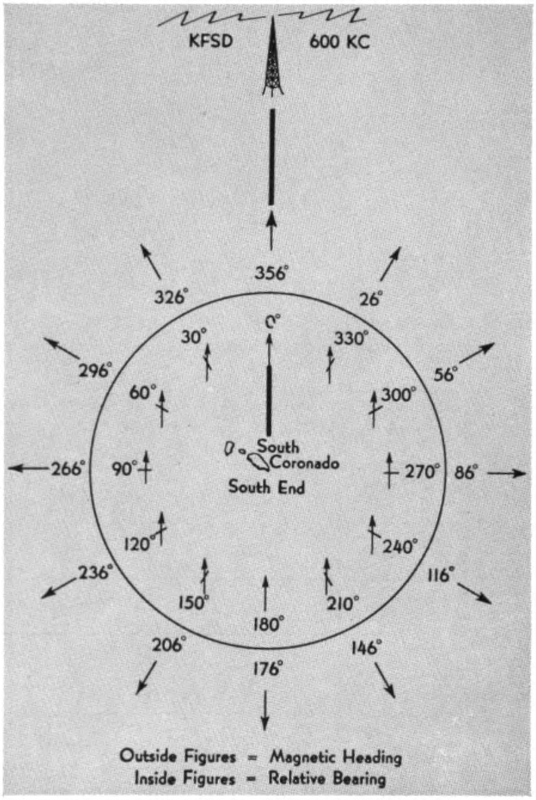


**FIG. 157—RADIO COMPASS CHECK**

from the first magnetic heading to the radio station, as shown in Figure 157.

To assist you in checking the radio direction finder, your captain steadies the PBY on each of the headings indicated on the diagram. At the instant the ship passes over the selected landmark, on each of the headings, he signals to the radio operator who then takes a relative bearing on KFSD while you double check the compass heading. Knowing the relative bearing, you then quickly determine the amount of calibration error, which equals the difference between the radio bearing taken and the correct relative bearing indicated on the diagram (Figure 157).

With the plane heading 266°, the radio operator took a relative bearing of 96°. By reference to the actual pre-computed bearing, this indicated at once that the direction finder was reading too large a value by 6°. Therefore, the calibration correction on this heading is minus 6°.



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## WEATHER FORECAST

Date 5-4-43

From San Diego To Honolulu Course 252° Plane Catalina GCT 2250

| | | ZONE 1 | ZONE 2 | ZONE 3 | ZONE 4 | ZONE 5 |
|---|---|---|---|---|---|---|
| WEATHER | | Clear | Clear | Ptly Cldy | Cldy | Ptly Shrs |
| CLOUDS | Type | Sctd | Sctd | .4 Sc | .7 Sc Cu | .6 Sc Cu |
| | Ceil. | 1000′ | 1500′ | 1500′ | 2000′ | 2000′ |
| | Tops | 2000′ | 3500′ | 6500′ | 7500′ | 7000′ |
| | Upper | X | X | Sctd 30,000′ | Sctd 14,000′ | Sctd 14,000′ |
| WIND | 1000′ | 310/12 | 320/12 | X | X | X |
| | 5000′ | 330/14 | 360/14 | 40/10 | 170/10 | 40/12 |
| | 7000′ | 320/12 | 360/14 | 120/10 | 310/14 | 10/7 |
| | 10,000′ | X | X | X | X | X |

No pronounced Fronts along course.

**San Diego**—2230 to 0230 GCT, no lower clouds, no upper clouds, surface winds 290°/8 kts., visibility 5/10 smoky, sea smooth.

**Terminal: Pearl Harbor**—1700 to 1900 GCT May 5th, partly showers, .6 Sc Cu at 2000′, tops at 7500′, high clouds sctd at 14,000′, surface winds 40°/12, visibility unlimited.

**Alternate: Hilo**—1600 to 1800 GCT May 5th, party showers, 6 Sc Cu at 1500′, tops at 8500′, high clouds sctd at 14,000′, surface winds 40°/14, visibility unlimited.

**Remarks**—Flight Time Analysis at 7000′, 19.8 hours to Pearl Harbor, 18.7 hours to Hilo.

Recommend a drift southward in early portion of flight since winds are more favorable to south of course.

**Signed:** Weather Officer

FIG. 158



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Calibrating the radio direction finder is an important procedure, for if you can take radio bearings that are reasonably accurate, you will be able to use them to check celestial fixes, or, under proper conditions, to employ such bearings alone to fix the ship's position. You should be able, if necessary, to direct your aircraft to its destination without radio. However, pilots who are accustomed to radio and contact flying over land begin to feel a little worried after flying for ten or fifteen hours without seeing anything but water. At such times, a radio bearing which checks your celestial fix is an added comfort to the crew—and even to yourself. Such bearings are a comfort to the navigator because occasionally a wind will blow your aircraft into an unbelievable position, and though you take celestial sights as often as possible in order to catch these sudden shifts of wind, it is not unusual to be blown 50 miles off course between fixes. You know that your celestial fixes are usually accurate. Nevertheless, when both a celestial fix and a radio bearing check, even if the check establishes your position as off course, everyone on board feels more confidence in your ability.

By 12:00 noon, your check flight is over. Engines, aircraft and radio are in perfect condition; the crew is satisfied they have a "good airplane."

The engineer has elected himself food supply officer and is off to town to obtain a supply of provisions. Since there is nothing left to check on the aircraft, the crew is temporarily at liberty.

**Final Forecast**—By 2:00 P. M. you would usually be back at the Airway's office, but due to the war you check in at the Naval Briefing Office for final briefing and weather forecast. Briefing means you'll be given the latest confidential data bearing on the proposed route. This includes instructions for receiving and sending messages and weather reports via radio, information on air base facilities, let-down and approach procedures and other restricted information. You are shown the latest weather map, and given a copy of the forecast (Figure 158) which estimates your flight time as 19.8 hours. However, you will recalculate it yourself and then plot a flight graph of time and fuel consumption. Use of this graph in flight will enable you to determine very quickly if the aircraft is flying according to the estimated forecast. It will indicate whether engines are using too much fuel and, if so, whether you can make your destination, or whether you will have to turn back. The graph also indicates the point of no return (PN), or "splash point," the times of sunrise and sunset, and location of weather fronts. Sometimes, for multi-engine aircraft, when engine data is available, you plot a second curve on the graph to show the PN in the event one of the engines fails.

**Note**: This weather forecast was based upon the latest weather maps, which, in turn,

ZONE BOUNDARIES—SAN DIEGO TO HONOLULU—COURSE 252°

| ZONE | BOUNDARIES | DISTANCE (Nautical Miles) | COURSES | |
|---|---|---|---|---|
| | | | MAGNETIC | TRUE |
| 1 | San Diego to 120°W | 153 | 237° | 252° |
| 2 | 120°W to 130°W | 540 | 237° | 252° |
| 3 | 130°W to 140°W | 555 | 237° | 252° |
| 4 | 140°W to 150°W | 577 | 240° | 252° |
| 5 | 150°W to PCY (Pearl Harbor, Honolulu) | 494 | 240° | 252° |
| | Total Distance | 2319 | | |

FIG. 159—COURSE ZONES



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were based upon all available weather reports received from ships, aircraft and weather stations along the proposed route. Therefore, in order that following flights also may have the benefit of a good forecast, the navigator should carefully and conscientiously observe weather encountered in flight, and report correct weather information by radio.

**Course Zones** — Looking at the forecast again, note that it is divided into five zones. The report found below each zone provides weather and wind predictions for that particular zone. Weather forecasting, at best, is only an estimate, and since weather reports over vast water areas are few and far between, definite wind predictions cannot be given for every mile of the course. As a result, the weather forecaster has divided the various air routes into several basic segments called zones (see Figure 159). Various zone boundaries are employed. Sometimes the zones are an even 5° of longitude in width; on the other hand they may cover 10° of longitude, depending upon the purposes and procedures of those originating the forecast. However, the general practice is to allow the amount and accuracy of available weather information in each area to determine the width of the zone. Where available weather reports are numerous and accurate, the area covered by each zone is relatively small. If only a few reports are available, the area included is greater. Usually the weather forecast states the boundaries and areas of each zone. However, zones are practically of standard dimensions, and the Operations Manual which is part of your equipment furnishes this information for your proposed route.

**Flight Time Analysis**—Your next job as navigator is to analyze the forecast. Analyzing the forecast involves applying the wind predicted for each forecast altitude to pre-determined true air speeds and course, thus gaining an estimate of expected ground speeds and flying time in each zone. When the information is arranged in some such form as illustrated in Figure 161, it is called the *Flight Time Analysis.*

The predetermined true air speeds, which are computed for standard temperature, can be had by inspection of air speed curves, (Figure 160) contained in your Operations Manual.*

*The Operations Manual contains a number of long-range cruising curves which have been computed by the aircraft manufacturer after years of research. These curves indicate engineering and flight data on long-range performance, fuel consumption, engine power settings (M.P. and r.p.m.), etc., for the aircraft under various conditions of gross weight, load and altitude. Of particular interest to the navigator are the air speed curves (Figure 160), and the fuel consumption curves (Figure

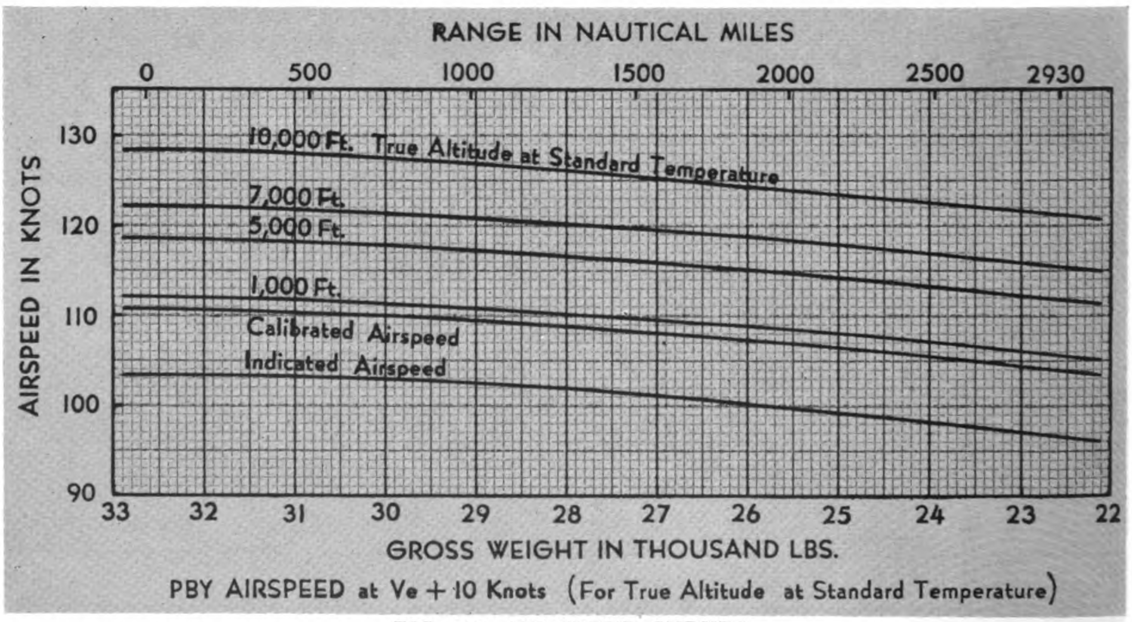


FIG. 160—AIR SPEED CURVES



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## FLIGHT TIME ANALYSIS

| | ZONE 1 | | | ZONE 2 | | | ZONE 3 | | | ZONE 4 | | | ZONE 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COURSE | 252 | | | 252 | | | 252 | | | 252 | | | 252 | | |
| ZONE DISTANCE | 153 | | | 540 | | | 555 | | | 577 | | | 494 | | |
| TOTAL DISTANCE | 153 | | | 693 | | | 1248 | | | 1825 | | | 2319 | | |
| | TAS | G.S. | TIME | TAS | G.S. | TIME | TAS | G.S. | TIME | TAS | G.S. | TIME | TAS | G.S. | TIME |
| ALTITUDE 1000′ | 112 | 105 | 1:28 | 112 | 107 | 5:03 | 111 | | | | | | | | |
| 5000′ | 118 | 115 | 1:20 | 118 | 122 | 4:26 | 117 | 126 | 4:25 | 116 | 114 | 5:04 | 115 | 125 | 3:57 |
| 7000′ | 122 | 117 | 1:19 | 122 | 126 | 4:17 | 121 | 128 | 4:20 | 119 | 111 | 5:12 | 118 | 121 | 4:05 |
| 10,000′ | | | | | | | | | | | | | | | |

## FLIGHT PLAN

| | | | | | |
|---|---|---|---|---|---|
| ALTITUDE | 7000′ | 7000′ | 7000′ | 7000′ | 7000′ |
| ZONE TIME | 1:19 | 4:17 | 4:20 | 5:12 | 4:05 |
| TOTAL TIME | 1:19 | 5:36 | 9:56 | 15:08 | 19:13 |
| GAS USED | 175 | 500 | 805 | 1160 | 1425 |
| GAS REMAIN | | | | | 325 |

RETURN 2 ENGINES COURSE 72°

ALTITUDE: 7000′ TOTAL AVAILABLE FUEL HOURS: 24.42 hrs. or 24h.25m.

| ZONE | T.A.S. | G.S. | ZONE TIME | TOTAL ZONE TIME | TOTAL FUEL HRS. *MINUS* TOTAL ZONE TIME | FUEL USED |
|---|---|---|---|---|---|---|
| 1 | 115 | 119 | 1:17 | 1:17 | 23:08 | 1670 |
| 2 | 116 | 111 | 4:52 | 6:09 | 18:16 | 1365 |
| 3 | 117 | 110 | 5:03 | 11:12 | 13:13 | 1030 |
| | | | | | | |

FIG. 161



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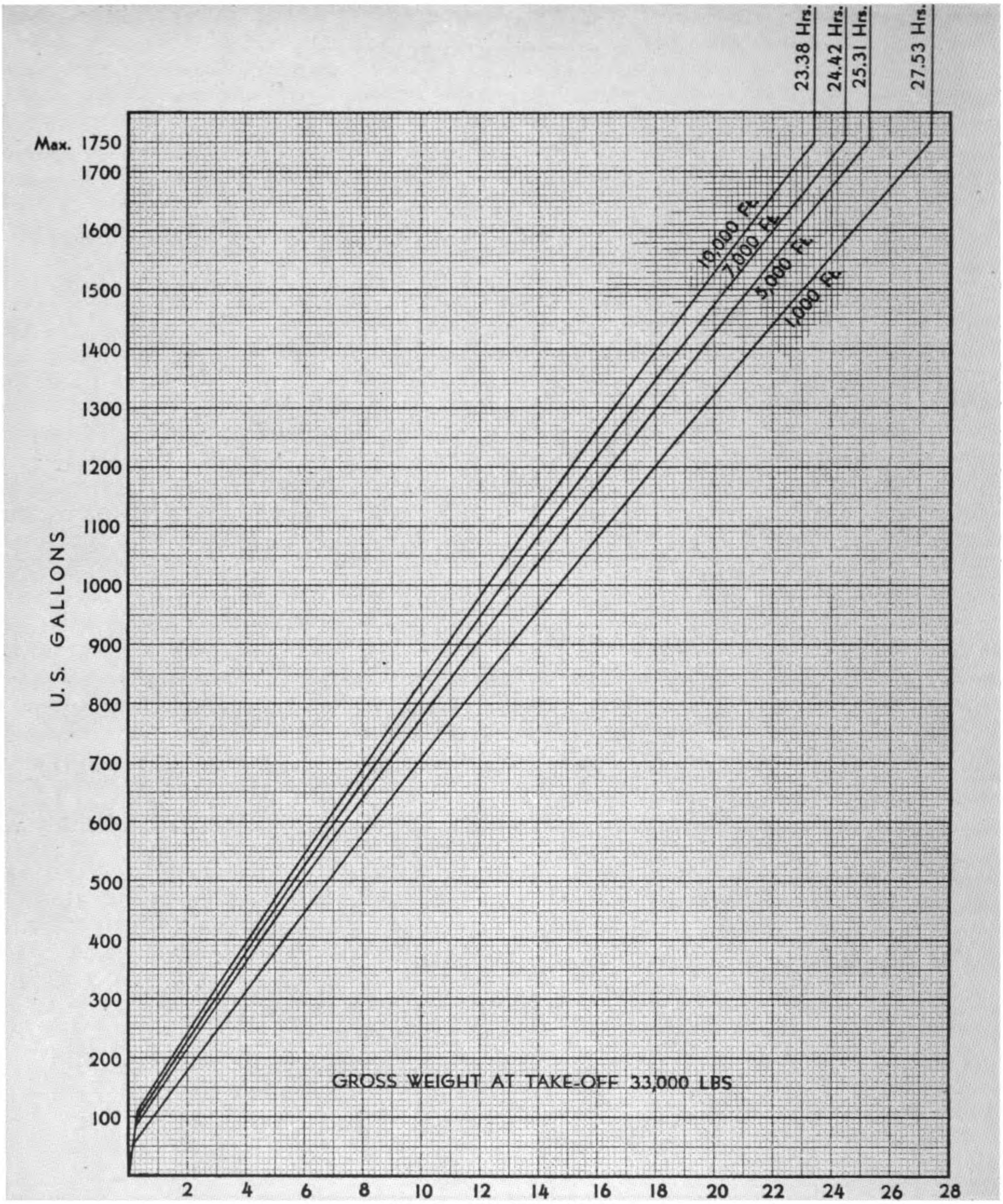


**HOURS OF CRUISING**

**PBY Fuel Consumption For Long Range Cruising Ve + 10 Knots**

FIG. 162—FUEL CONSUMPTION CURVES

162), as these are necessary for long-range forecasting. Notice in Figures 160 and 162 that these curves are for $V_e$ + 10 knots performance. $V_e$ indicates the effective velocity (indicated air speed) at which the aircraft would have to be flown in order to make good *maximum flying hours*. $V_e$ curves are used only for *endurance flights* because it has been proven that when there is a wind blowing, which is usually the case, *greater range* can be attained by increasing the power on the engines slightly in order to indicate an air speed 10 knots faster than $V_e$, hence $V_e$ + 10 knots. For this reason $V_e$ + 10 knots curves are generally used for all long-range flights.



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**Flight Plan**—You then carefully analyze the Flight Time Analysis to ascertain the most desirable cruising altitude, and begin to make out the Flight Plan (Figure 161). Normally, it is desirable to select that cruising altitude which will make possible the shortest flying time; however clouds, fronts, temperature and icing level may make it advisable to select a "slower" altitude, where safer, better flying conditions prevail. For today's Flight Plan you use 7000′, because at this altitude you should be able to keep above the clouds and stay in clear weather all the way. Totalling the zone times gives you $19^h13^m$, indicating that you actually have a *19.2 hour forecast* and not 19.8 as stated by the meteorologist.

In order to complete the Flight Plan you refer to the $V_e$ + 10 knots fuel consumption curves (Figure 162), also contained in the Operations Manual, and find, using the 7000′ curve, the amount of fuel which would be consumed by the end of each zone. The flight plan now indicates that if the flight forecast is accurate, your PBY will use a total of 1425 gallons of fuel and have in reserve 325 gallons on arrival at Honolulu.

**Return Flight Plan**—A plan for the return flight also is prepared because this information is to be plotted on a flight graph (Figure 163) which provides an ideal method of establishing the amount of reserve fuel needed for safe operation, as well as the radius of action and point of no return.

Several steps are necessary in preparing the Return Flight Plan (Figure 161).

First, you re-compute the Flight Analysis for the first half of the flight, using:

1. Reciprocal course.
2. The forecast winds (Figure 158) at the altitude most favorable for the return course.
3. Pre-determined true air speeds (Figure 160).*

Second, you total the zone times and find the length of time required to return to base from the end of zone one, zone two, and zone three.

Third, obtain the maximum flying time from the fuel consumption curve (Figure 162). In this case, your aircraft can fly 24.42 hours or $24^h25^m$, as this is the time indicated at the end of the 7000′ curve on which your forecast is based.

Fourth, subtracting the total zone time (time required to return to base from each zone) from maximum fuel hours, you find the total possible hours you could fly in order to reach the end of each zone, and still be able to reach your base.

Finally, using total flying hours, obtain from the fuel consumption curve (Figure 162) the total fuel that could be used to reach the end of each zone.

**Flight Graph**—With the flight plans completed, the final step is to plot the computed data in the form of a flight graph (called by many air navigators the "Howgozit"), which will permit a constant, clear check during the flight. The procedure for making the Flight Graph (Figure 163) is as follows:

a. On a sheet of graph paper of convenient scale, establish a *course distance scale* along the lower edge.

b. Mark off the *forecast zones* as shown.

c. Establish a *fuel consumption scale* along the left edge.

d. On the zone lines, mark the total fuel used at the end of each zone (as computed in the Flight Plan) and draw in the *fuel vs. miles* curve. This curve provides the most important information found on the graph, as it indicates the distance flown by the aircraft with relation to fuel consumed.

e. Establish a *time scale* along right edge. The scale, on this preliminary layout, should indicate only hourly intervals as the GCT takeoff time will have to be known before the actual time scale can be established.

Note that in this instance the time scale is started above the fuel scale, to keep the fuel

*Notice in Figure 160 that the air speed decreases as the range increases. This increase occurs because the aircraft is continuously losing weight as fuel is consumed, and as the weight decreases, flight efficiency increases. That is, the air speed and engine power can be reduced, resulting in less fuel consumption, while the aircraft will continue to maintain the same cruising performance ($V_e$ + 10 knots). Therefore, in order to obtain correct information from the air speed curves (Figure 160), and from the fuel consumption curves (Figure 162), you assume that the aircraft already has flown the first half of its maximum range prior to preparation of the Return Flight Plan.



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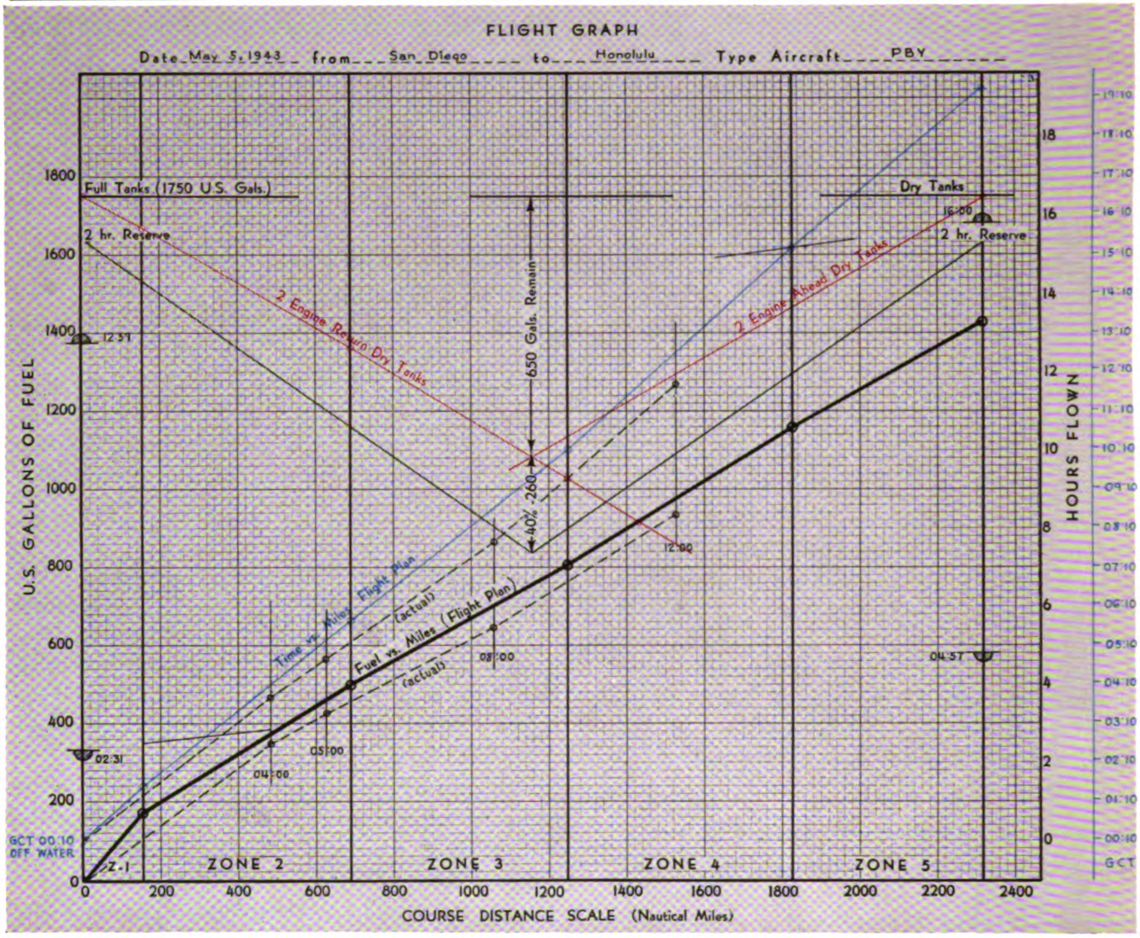


FIG. 163—FLIGHT GRAPH

curve and time curve (to be drawn) separated, thus permitting easier reading.

f. On the zone lines mark the total forecast time to the end of each zone (Flight Plan) and draw in the *time vs. miles* curve.

g. On the zone lines mark the total return fuel used to the end of each return zone (Return Flight Plan), and commencing at point of full tanks, draw in the *two-engine return dry tanks* curve. The intersection of this curve, extended, with the fuel vs. miles curve locates the PN.

h. From the point of dry tanks (at destination), draw a line parallel to the fuel vs. miles curve. This line is the *two engine ahead dry tanks* curve. The point at which the two dry tanks curves intersect represents the absolute maximum amount of fuel the aircraft can consume and still return or go ahead to destination.

i. Determine amount of fuel remaining at point where dry tanks curves intersect, and from this point, at a distance equal to 40% of the remaining fuel, locate a second point vertically beneath the point of intersection.

j. Obtain from fuel consumption curve (Figure 162) amount of fuel required for final two hours cruising. Mark this amount on Flight Graph below *full tanks* and *empty tanks* points and draw in *40% to 2 hours reserve ahead* and *return* curves. These curves represent safe flying curves, and any position below these curves would be considered safe.

k. In airline operations it is especially important also to plot on the Flight Graph the maximum amount of reserve fuel required on arrival at destination. As an example, four hours reserve fuel is ample safe allowance for



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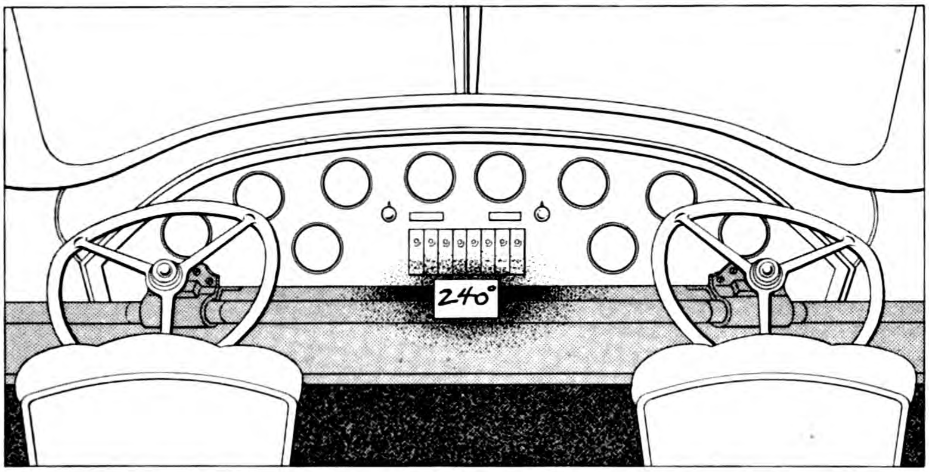


FIG. 164—HEADING MEMORANDUM FOR PILOT

your PBY. Plotting this amount on the Flight Graph you see from the relationship of this amount to the fuel vs. miles curve that you are carrying 75 gallons of fuel over and above the required reserve. Converted into cargo weight, 75 gallons of fuel is equivalent to approximately 450 pounds. In other words, the Flight Graph proves it would be safe to carry 75 gallons less fuel, thus allowing the aircraft to carry two or three extra passengers. It is easy to see that similar additional payloads on all flights would, in the course of a year, amount to many thousands of dollars additional income for the airline.

**Note:** The average time required to make up one of these flight forecasts and flight graphs is thirty to forty minutes, and its value is inestimable. An airline could not afford to neglect it, and its correct use in flight makes it practically impossible for an aircraft to run out of fuel except through mechanical failure.

**Departure Clearance**—3:30 P. M.—The co-pilot, radio operator and engineer are at the aircraft waiting for take-off. You and the captain are at the Airway's office receiving last minute instructions, customs papers, bill of health, clearance papers, cargo and mail manifests.

The flight clearance approved, you are on your way. With wide-open throttles your plane roars down the bay, rapidly picking up speed—70 . . . 80 . . . 90 knots. Gradually the spray stops flying past the windshield. The next moment the ship is clear of the water, and the earth appears to drop away.

**Off the Water**—May 5, 1943—00:10 GCT. In the excitement of take-off you almost forgot to read the time!

The captain's first question will be, "What is our heading?" You have the answer ready for him, having worked it out in advance. (This and other vector problems will be solved on the computer to save time).

| | |
|---|---|
| 252° | True Course |
| —15° E | Variation |
| 237° | Magnetic Course |
| +5° L | Drift (from forecast wind—320°/12 knots) |
| 242° | Magnetic Heading |
| —2° E | Deviation |
| 240° | Compass Heading to fly |

You have found from experience that it is a good rule to write the heading on a slip of paper and stick it on the controls where the captain and co-pilot can see it easily (Figure 164).

By now San Diego is far behind. The plane is climbing steadily, higher and higher into the sky. Everyone is in excellent spirits.

**00:29 GCT**—Nineteen minutes from take-off—your aircraft is now leveling off at 7000′ as per forecast. The captain is pulling back on the throttles, adjusting them and the propeller pitch so that the manifold pressure and revolutions per minute are for $V_e + 10$ cruising range, as per engine performance graph.



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The reduced power now makes the engines relatively quiet. The engineer has changed the fuel mixture from full rich to automatic lean. The radio operator is sending in the departure time to the shore watch station.

Flight routine has begun.

**Navigator's Flight Report**—Your first job is to start filling out the Navigator's Flight Report (see example, Figure 166) to which you will refer each hour, filling in the hourly record. From this report you will check courses, positions, and make up the radio reports. After the flight is over it will be given to the Airway's office so they can keep a record of the flight.

In order to save time, the type of position is given a numerical designation as follows:

1. Dead Reckoning Position.
2. Approximate Fix (Single position line and DR, or radio bearings).
3. Fix (Celestial or Visual)

**Chart Preparation**—Before starting to navigate it is advisable, in order to save time, to draw in the course line marked off in units of 100 nautical miles, and indicate the zone boundaries and forecast winds (Figure 165).

**First Position Report**—You are now ready to find the 01:00 GCT position. It is a common belief that an aerial navigator has to be extremely fast in his work. While it is true that the ability to calculate rapidly is certainly an asset to the navigator, accuracy and common reasoning are far more important. Navigation is not an exact science, particularly aerial navigation, but it does give an approximate position which is sufficiently accurate with relation to the aircraft's speed for all practical purposes. Bearing in mind the limitations of aerial navigation, it is the navigator's job to know which of the various navigational methods, or combination of methods, will enable him to most accurately determine the aircraft's position with the least effort.

The sun is setting in the West, and if an observation of the sun were taken, it would give you a single line of position which would serve as a fair speed check. However, during the climb you kept track of the indicated air speed, which averaged 98 knots. The indicated air speed now is 103 knots. Since the forecast wind force and direction usually is quite accurate for the first zone, and since you are less

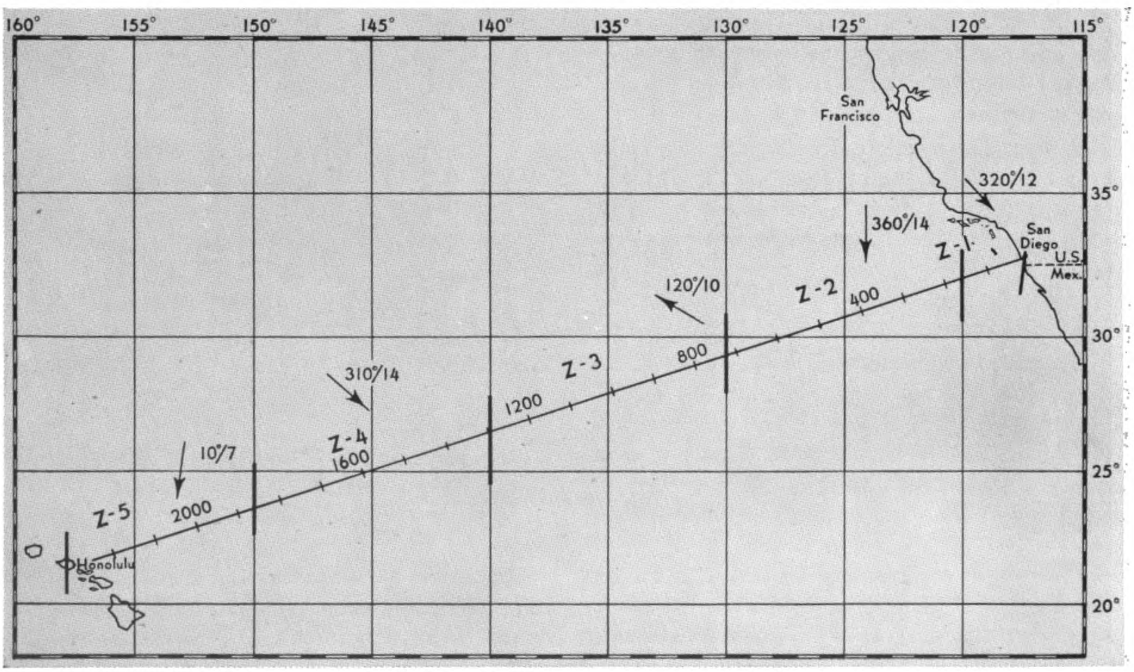


FIG. 165—CHART PREPARATION



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## NAVIGATOR'S FLIGHT REPORT

TRIP NO. ............ DATE ............ CAPTAIN ............ CO-PILOT ............

ORIGIN ............ DESTINATION ............ NAVIGATOR ............ RADIOMAN ............

PLANE NO. ............ TYPE ............ RADIO CALL ............ ENGINEER ............

| TIME | POSITION | | | AIR SPEED | | | ALTITUDE | Temp. | Course | DRIFT | True | VARIATION | DEVIATION | Comp | WIND | | GROUND | TIME | DISTANCE | | GASOLINE | | | WEIGHT | M.P. | R.P.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G.C.T. | Lat. | Long. | TYPE | IAS | CAS | TAS | | °C. | or Track | | Head | | | Head | Dir. | Vel. | SPEED | ELAPSED | Flown | To Go | Rate Cons. | Used | Remain | | | |
| 00:10 | OFF | WATER | SAN DIEGO | | | | | | 252 | 5L | 257 | 15E | 2E | 240 | 310 | 12 | 104 | | | 2319 | | | 1750 | 33,000 | | |
| 00:29 | END | OF CLIMB | | | | | 7000 | +5 | | | | | | | | | | 0:19 | 33 | 2286 | | | | | 28.0 | 1980 |
| 01:00 | 32-15 | 118-55 | 1 | 103 | 110 | 123 | 7000 | +5 | 252 | 5L | 257 | 15E | 2E | 240 | 320 | 12 | 117 | 0:50 | 94 | 2225 | | 120 | 1630 | | 28.0 | 1980 |
| 02:00 | 31-25 | 121-10 | 2 | 103 | 110 | 123 | 7000 | +5 | 249 | 8L | 257 | 15E | 2E | 240 | 360 | 19 | 127 | 1:50 | 220 | 2099 | 77 | 197 | 1553 | | 28.0 | 1980 |
| 03:00 | 30-40 | 123-30 | 1 | 103 | 110 | 123 | 7000 | +6 | 249 | 8L | 257 | 15E | 2E | 240 | 360 | 19 | 127 | 2:50 | 350 | 1969 | 76 | 273 | 1477 | | 28.0 | 1980 |
| 04:00 | 29-35 | 125-55 | 3 | 103 | 110 | 123 | 7000 | +6 | 247 | 10L | 257 | 15E | 2E | 240 | 360 | 23 | 128 | 3:50 | 485 | 1834 | 75 | 348 | 1402 | 30,912 | 27.0 | 1950 |
| 05:00 | 28-55 | 128-40 | 3 | 103 | 110 | 123 | 7000 | +4 | 252 | 5L | 257 | 15E | 2E | 240 | 40 | 20 | 139 | 4:50 | 630 | 1689 | 75 | 423 | 1327 | | 27.0 | 1950 |
| 06:00 | 28-15 | 131-10 | 1 | 103 | 110 | 123 | 7000 | +4 | 253 | 0 | 253 | 14E | 2E | 237 | 70 | 16 | 139 | 5:50 | 775 | 1544 | 74 | 497 | 1253 | | 27.0 | 1950 |
| 07:00 | 27-35 | 133-40 | 1 | 102 | 109 | 123 | 7000 | +10 | 253 | 0 | 253 | 14E | 2E | 237 | 70 | 16 | 139 | 6:50 | 915 | 1404 | 74 | 571 | 1179 | 29,574 | 26.5 | 1930 |
| 08:00 | 27-15 | 136-20 | 3 | 102 | 109 | 123 | 7000 | +10 | 256 | 3R | 253 | 14E | 2E | 237 | 100 | 18 | 140 | 7:50 | 1060 | 1259 | 74 | 645 | 1105 | | 26.5 | 1930 |
| 09:00 | 26-35 | 138-50 | 1 | 102 | 109 | 123 | 7000 | +10 | 252 | 0 | 252 | 14E | 2E | 236 | 70 | 17 | 140 | 8:50 | 1195 | 1124 | 73 | 718 | 1032 | | 26.5 | 1930 |
| 10:00 | 26-15 | 140-45 | 3 | 102 | 109 | 123 | 7000 | +10 | 255 | 3R | 252 | 14E | 2E | 236 | 130 | 07 | 126 | 9:50 | 1300 | 1019 | 73 | 791 | 959 | | 26.5 | 1930 |
| 11:00 | 25-35 | 142-50 | 1 | 102 | 109 | 123 | 7000 | +10 | 250 | 1L | 251 | 13E | 2E | 236 | 300 | 05 | 120 | 10:50 | 1420 | 899 | 72 | 863 | 887 | | 26.5 | 1930 |
| 12:00 | 24-45 | 144-35 | 3 | 102 | 109 | 123 | 7000 | +10 | 248 | 3L | 251 | 13E | 2E | 236 | 280 | 12 | 113 | 11:50 | 1530 | 789 | 71 | 934 | 816 | | 26.5 | 1930 |
| 13:00 | 24-15 | 146-40 | 1 | 101 | 108 | 122 | 7000 | +10 | 254 | 5L | 259 | 12E | 2E | 245 | 310 | 14 | 116 | 12:50 | 1650 | 669 | 70 | 1004 | 746 | | 26.5 | 1930 |
| 14:00 | 23-35 | 148-45 | 3 | 101 | 108 | 122 | 7000 | +10 | 252 | 7L | 259 | 12E | 2E | 245 | 340 | 15 | 122 | 13:50 | 1770 | 549 | 70 | 1074 | 676 | 26,556 | 26.0 | 1880 |
| 15:00 | 22-55 | 151-00 | 3 | 101 | 108 | 122 | 7000 | +10 | 252 | 7L | 259 | 12E | 2E | 245 | 10 | 16 | 128 | 14:50 | 1905 | 414 | 68 | 1142 | 608 | | 26.0 | 1880 |
| 16:00 | 22-20 | 153-15 | 1 | 101 | 108 | 122 | 7000 | +10 | 256 | 7L | 263 | 12E | 2E | 249 | 10 | 16 | 128 | 15:50 | 2035 | 284 | 68 | 1210 | 540 | | 26.0 | 1880 |
| 17:00 | 21-50 | 155-25 | 2 | 101 | 108 | 122 | 7000 | +10 | 256 | 6L | 262 | 11E | 2E | 249 | 10 | 16 | 128 | 16:50 | 2160 | 159 | 67 | 1277 | 473 | | 26.0 | 1880 |
| 18:29 | ON WATER | HONOLULU | | | | | | | | | | | | | | | | 18:09 | 2319 | | 103 | 1380 | 370 | | | |

FIG. 166



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than an hour out, a DR position will be just as accurate as a celestial line of position, and easier to determine.

Referring to the Performance Manual (Figure 160), the air speed calibration correction is found to be +7 knots. Therefore, the calibrated air speed during the climb was 105 knots, and now is 110 knots. The temperature, read off the instrument panel, is +5°C. Using these calibrated air speeds, and with the computer set at +5°C and at about 3000′ for the climb and 7000′ for your present altitude, you find the true air speeds flown to be 109 knots on the climb and 123 knots at 7000′.

Applying the forecast wind (Figure 158) to the true air speeds (using the computer) gives the following ground speeds:

104 knots—Ground speed during climb
118 knots—Ground speed at 7000′

Using this information you compute the distance flown as follows:

a. 00:10 Off water
00:29 End of climb
19 minutes elapsed during climb

b. 19 minutes @ G.S. 104 knots = 33 NM

c. 00:29 End of climb
01:00 Time of position desired
31 minutes elapsed since climb

d. 31 minutes @ G.S. 118 knots = 61 NM

e. 33 NM
+61 NM
94 NM = Distance flown along course from point of departure to DR position at 01:00 GCT.

Measuring along the course a distance of 94 miles from point of departure, you find that the 01:00 GCT DR position is latitude 32°15′ North, longitude 118°55′ West (Figure 168).

Fill in the Navigator's Flight Report (Figure 166).

**DR Ahead**—As it is good practice always to know the airplane's estimated position at least one or two hours in advance, you step off the DR positions for 02:00 and 03:00 o'clock GCT. Both of these positions will be in Zone 2. Until you have a fix to definitely determine the wind, refer back to the forecast wind which is 360°/14 knots. Since the true air speed is

**FIG. 167—LEVELED OFF AT 7000′**

still 123 knots, and course 252°, you obtain a ground speed of 127 knots and drift of 6° left.

Next, using the mid-latitude scale (Figure 168) opposite the distance to be measured, set the dividers to 127 knots ground speed and step off two points from the 01:00 position. Mark these two points 02:00 DR and 03:00 DR respectively. The actual position of the plane at these two times will probably be south of the course since you are only allowing 5° left drift. However, these are only estimated positions to be revised later when more exact information is found.

**01:48 GCT**—The radio operator is listening to KFSD, San Diego, so you decide to take a radio bearing which will give you a good check on the drift, as the station lies directly on the course.

A radio bearing taken at the aircraft is the relative bearing of the radio station measured clockwise from the nose of the aircraft. Therefore, at the instant the radio operator takes the bearing of the radio station, he signals and you read the compass heading.

He finds the bearing to be 163°, and the compass heading which you simultaneously noted was 241°. Checking the radio calibration graph you find a correction of +7° for a relative bearing of 163°, making the correct relative bearing 170°.

The next step is to find the true bearing (Figure 169) to which the Mercator correction is then applied in order to obtain the Mercator bearing. This procedure is as follows:



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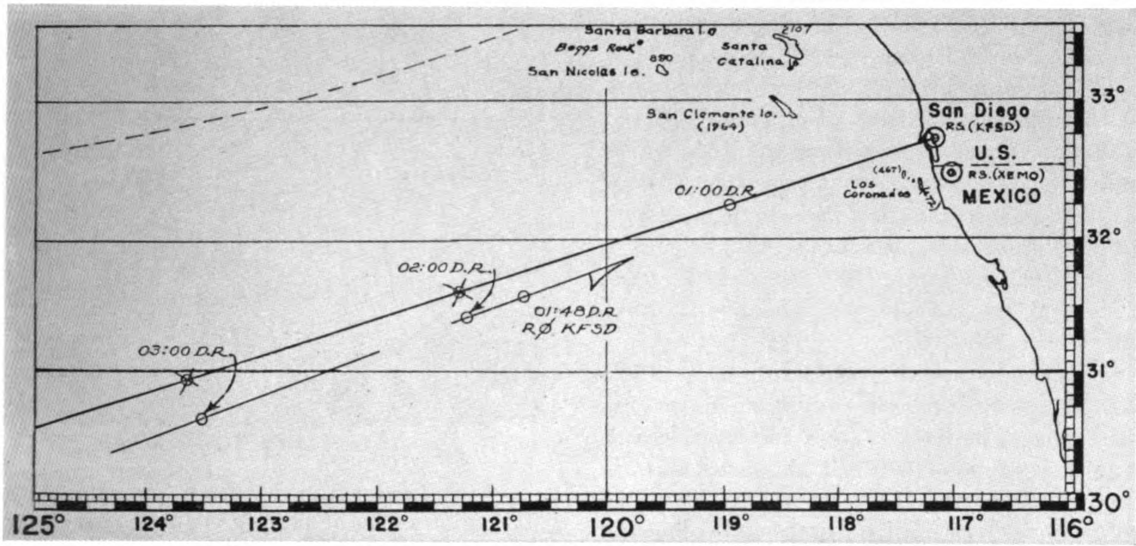


FIG. 168—01:00, 02:00, AND 03.00 GCT POSITIONS

| | |
|---|---|
| 241° | Compass heading |
| + 15° E | Variation (found on chart) |
| 256° | Magnetic heading |
| + 2° E | Deviation (from deviation card) |
| 258° | True heading |
| +170° | Correct relative bearing |
| 428° | |
| —360° | |
| 68° | True (great circle) bearing of KFSD |
| + 1° | Mercator correction |
| 69° | Mercator bearing of KFSD from aircraft |

The reciprocal of 69° then is plotted on the chart from KFSD, and a DR position established on the bearing line for 01:48, the time the bearing was taken (Figure 168).

You notice that the position thus obtained is about 12 miles south of the course. Assuming that the radio bearing is correct, you conclude that the wind has changed. On measuring the track made good from departure, you find it to be 249°, or 3° less than the track you intended to fly. Therefore, the drift has been 8° left instead of the 5° left you allowed.

To be 12 miles off course is not considered serious in aerial navigation, and since

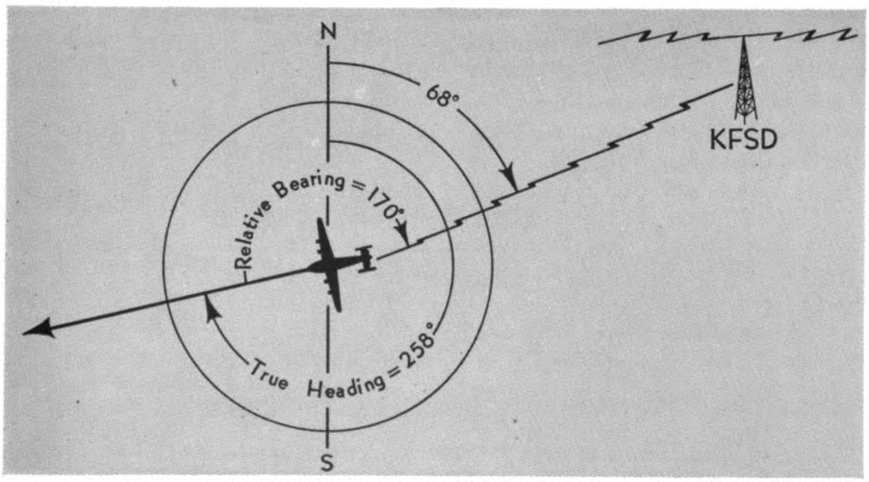


FIG. 169—COMPUTING RADIO BEARING FROM KFSD



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the forecast recommended drifting south of the course for more favorable winds, you decide to hold the same heading (240°) until a more definite fix is established. Also to be considered is the forecast wind shift in the next zone which will tend to blow the aircraft back on course.

Advancing the 01:48 position to 02:00 GCT (Figure 168), you fill in the Navigator's Flight Report (Figure 166), entering the forecast wind, track made good and temperature, which now is +6°C.

You now re-establish the 03:00 position and fill in the Navigator's Flight Report for that time. The data (except for latitude and longitude of position) will be identical with that found for the 02:00 report, as there will be no more fixes until the stars are visible.

(Erase the previously estimated 02:00 and 03:00 DR positions).

Using the information on the Navigator's Flight Report sheet, you now prepare the Radio Weather Report using the information obtained at briefing, carefully noting the prevailing weather conditions, especially cloud formations and temperature.

Next, you refer to the Flight Graph (Figure 163) and fill in the GCT scale for the time vs. miles curve, with the GCT time of take-off as starting point. Then you find in the Air Almanac the times of sunrise and sunset for both San Diego and Honolulu, and mark them on the graph as illustrated, using the time and distance scales. Connecting the two sunset and sunrise points with a ruler, you draw short lines where the ruler crosses the time vs. miles curve. These lines indicate the approximate time and position along course at which you may expect sunset and sunrise to occur. They also indicate the duration of night flying. Your curve shows that sunset will occur at about 02:50 GCT.

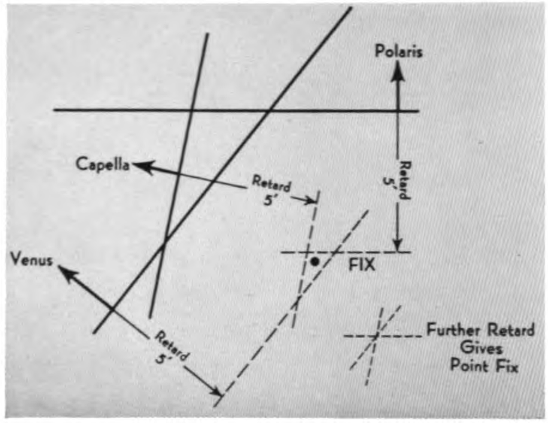


**FIG 170—ANALYZING YOUR FIRST FIX**

**03:00 GCT**—The sun has set and the stars are beginning to be plainly visible. You study the sky to determine which of the celestial bodies will afford the best fix. Venus is the first body selected because it is nearly ahead and very bright, thus serving as an excellent speed line sight. (Speed is most important to establish at this time, as it will help check the fuel consumption). Because it is also desirable to know the aircraft's definite position, Polaris, which is easiest to compute, is selected for a latitude and course check. Then a third celestial body, Capella, whose position line will cross the other two at a good angle, is selected to check the other two position lines and make a good three-line fix.

Next, you select a comfortable spot in the aircraft, usually the pilot's or co-pilot's seat, where you can easily observe all three bodies.

Adjusting the octant to the body's approximate altitude, you observe Polaris first, since it is the least brilliant of the three bodies and most difficult to sight in the octant. Then, Capella is shot and, last, the speed sight, Venus.

Their altitudes measured, you proceed to find the resultant lines of position (by H.O. 214 in this case).

**POLARIS**

| | | |
|---|---|---|
| GCT $03^h12^m15^s$ | | |
| | | 269°37′ |
| | | 0°35′ |
| GHA ♈ | = | 270°12′W |
| DR Long. | = | 124°12′W |
| LHA ♈ | = | 146° W |

| | | |
|---|---|---|
| Hs | = | 29°51′ |
| Ref. | = | —1′ |
| Ho | = | 29°50′ |
| Corr. LHA ♈ | = | +30′ |
| **Latitude** | = | 30°20′N |



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**CAPELLA**

GCT $03^h15^m07^s$

| | | |
|---|---|---|
| | | 269°37′ |
| | | 1°17′ |
| | | 281°53′ |
| GHA | = | 552°47′ |
| | | —360° |
| GHA | = | 192°47′ |
| **Assumed Long.** | = | 124°47′W |
| LHA | = | 68° W |
| **Assumed Lat.** | = | 30° N |
| Dec. | = | 45°56′N |

Lat. 30°N
Dec. 46°N
Same name

| | | |
|---|---|---|
| Hs | = | 35°39′ |
| Ref. | = | —1′ |
| Ho | = | 35°38′ |
| Hc | = | 35°47.7′ |
| a | = | **9.7′ away** |
| Δd | = | .14′ (x 4′ = .6′) |
| H | = | 35°48.3′ |
| Δd corr. | | —.6′ |
| Hc | = | 35°47.7′ |
| Az | = | **N 52.5°W** |

**VENUS**

GCT $03^h18^m07^s$

| | | |
|---|---|---|
| | | 187°44′ |
| | | 2°02′ |
| GHA | = | 189°46′ |
| **Assumed Long.** | = | 124°46′W |
| LHA | = | 65° W |
| **Assumed Lat.** | = | 30° N |
| Dec. | = | 25°15′N |

Lat. 30°N
Dec. 25°N
Same name

| | | |
|---|---|---|
| Hs | = | 32°47′ |
| Ref. | = | —1′ |
| Ho | = | 32°46′ |
| Hc | = | 32°58.6′ |
| a | = | **12.6′ away** |
| Δd | = | .35 (x 15′ = 5.2′) |
| H | = | 32°53.4′ |
| Δd corr. | | +5.2′ |
| Hc | = | 32°58.6′ |
| Az | = | **N 78°W** |

You then plot these three lines of position on the chart (Figure 171), Venus first, then Capella and finally Polaris, advanced to give a fix at 03:18 GCT, the time at which Venus was observed.

**Analyzing Fix**—You notice that the three position lines form a small triangle, establishing, for all practical purposes, the aircraft's position for the time of the fix as being in the center of the triangle. However, the careful navigator analyzes each of his fixes to determine the reasons, if any, why he did not get a point fix. Rechecking your work carefully you find no mathematical errors. It occurs to you, therefore, that the octant may have some instrument error not accounted for.

Checking the position lines (Figure 170), you quickly see that if each was retarded along its azimuth line, the triangle would be reduced in size, eventually becoming a point fix. But if these lines were so retarded, you would be presuming that the error was entirely due to unknown instrument error, and that all of your sights were accurate. You feel, however, that, actually, the Polaris sight was somewhat inaccurate since it was dim and consequently difficult to observe. Therefore, you estimate the amount of instrument error as 5′ and retard each of the lines by this amount. The resulting triangle is quite small, although lying outside the original triangle, but should much more accurately represent your true position.

This fix shows you to be 30 miles south of the course, making good a track of 247° with a ground speed of 128 knots and drift 10° left. Setting this up on the computer against true air speed you determine the wind to be 360°/23 knots.



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Since the speed has increased, you are getting the more favorable wind forecast by keeping south of the course, so you decide to hold the same heading. Advancing this fix to 04:00 GCT on the new course of 247°, at a ground speed of 128 knots, you fill in the Navigator's Flight Report (Figure 166) and make up the Radio Weather Report so it may be sent in on the hour.

Referring to the Flight Graph (Figure 163), you then plot in the actual data in dotted lines alongside the pre-computed curves. This information for 04:00 GCT is as follows:

*Time vs. Miles Curve*
Time $3^h50^m$
Distance 485 NM

*Fuel vs. Miles Curve*
Fuel 348 gals.
Distance 485 NM

Since both of these actual curves fall below the estimated curves, the ship is making better time and using less fuel than was forecast.

**04:30 GCT**—Having just eaten a tasty steak sandwich which the engineer cooked up in fine style on the electric grill, you are feeling 100% better. By now members of the crew have settled down to the definite routine of a long-range flight. The motors drone monotonously as you fly on and on, steadily and surely eating up the miles between San Diego and Pearl Harbor. There is little feeling of forward movement when flying, especially at high altitudes or at night. In a train you can note your movement by watching telephone poles whiz by—but there are no phone poles up here!

Anxious now to check up on the 10° left drift you still are allowing for, you scan the sky to see what stars are available for a sight. Though it is beginning to cloud up, there are still plenty of stars out so you decide to shoot Polaris once more for a drift check. Since it is always good policy to select three bodies and plot a definite fix while you are at it, you also shoot Regulus for a speed check and Capella to complete the fix.

**POLARIS**

| | | | | | |
|---|---|---|---|---|---|
| GCT $04^h36^m07^s$ | | | $H_s$ | = | 28°29′ |
| | | 289°41′ | I. C. | = | —5′ |
| | | 1°32′ | Ref. | = | —1′ |
| GHA ♈ | = | 291°13′W | $H_o$ | = | 28°23′ |
| DR Long. | = | 127°30′W | Corr. LHA ♈ | = | +45′ |
| LHA ♈ | = | 163°43′W | **Latitude** | = | 29°08′N |

**CAPELLA**

| | | | | | |
|---|---|---|---|---|---|
| GCT $04^h39^m07^s$ | | | $H_s$ | = | 23°12′ |
| | | | I. C. | = | —5′ |
| | | 289°41′ | Ref. | = | —2′ |
| | | 2°17′ | $H_o$ | = | 23°05.0′ |
| | | 281°53′ | $H_c$ | = | 23°00.2′ |
| GHA | = | 573°51′ | a | = | **4.8′ toward** |
| | | —360° | | | |
| GHA | = | 213°51′ | Δd | = | .32 (x 4′ = 1.3′) |
| **Assumed Long.** | = | 127°51′W | H | = | 23°01.5′ |
| LHA | = | 86° W | Δd corr. | | —1.3′ |
| **Assumed Lat.** | = | 29° N | $H_c$ | = | 23°00.2′ |
| Dec. | = | 45°56′N | Az | = | **N 48.8°W** |

Lat. 29°N
Dec. 46°N
Same name



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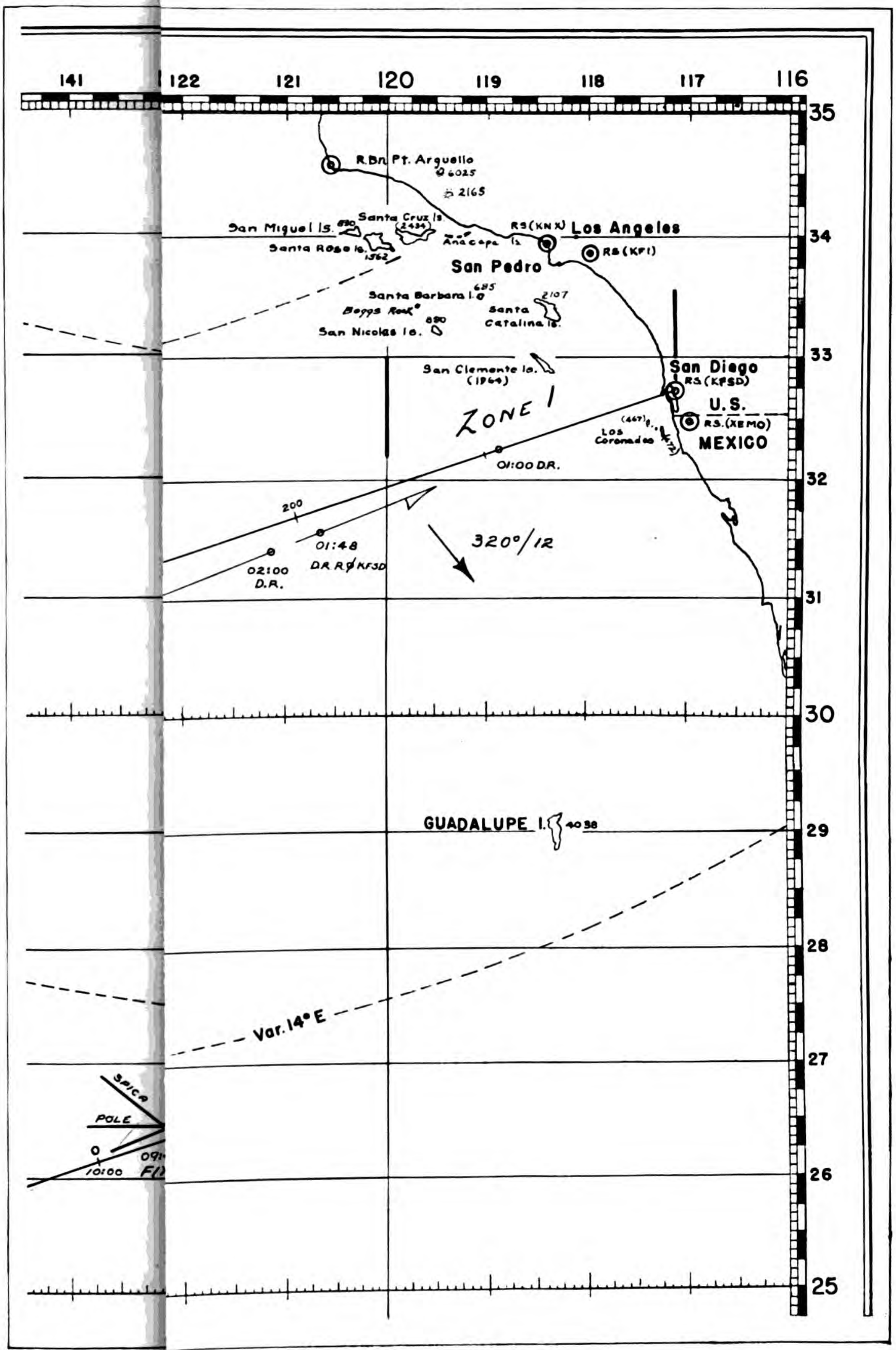


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**REGULUS**

GCT $04^h42^m07^s$

| | | |
|---|---|---|
| | | 292°11′ |
| | | 0°32′ |
| | | 208°40′ |
| GHA | = | 501°23′ |
| | | —360° |
| GHA | = | 141°23′ |
| **Assumed Long.** | = | 127°23′W |
| LHA | = | 14° W |
| **Assumed Lat.** | = | 29° N |
| Dec. | = | 12°15′N |

| |
|---|
| Lat. 29°N |
| Dec. 12°N |
| Same name |

| | | |
|---|---|---|
| $H_s$ | = | 69°00′ |
| I. C. | = | —5′ |
| Ref. | = | 0′ |
| $H_o$ | = | 68°55′ |
| $H_c$ | = | 68°46.8′ |
| a | = | **8.2′ toward** |
| $\Delta$d | = | .82 (x 15′ = 12.3′) |
| H | = | 68°34.5′ |
| $\Delta$d corr. | | +12.3′ |
| $H_c$ | = | 68°46.8′ |
| Az | = | **N 139.6°W** |

These three lines of position crossing in a point fix prove that you correctly analyzed the last fix, and that your octant actually has an instrument error of about 5′.

Measuring the track and ground speed from the last fix indicates that the wind is shifting around, as forecast.

Advancing the fix to 05:00 GCT you fill in the Navigator's Flight Report, using the track and wind found. Then, after compiling the Radio Weather Report, you plot in the actual data on the Flight Graph.

The temperature has dropped to +4°C. and the sky now is overcast, making it impossible to take any more sights, so you estimate the 06:00 and 07:00 positions (Figure 171).

Since the temperature has lowered, you are probably passing through a mild front which is the reason for the wind shift. Knowing the wind is shifting, you estimate it as 70°/16 knots. Laying out a new course to your destination (253°) you fill in the 06:00 GCT Navigator's Flight Report. Calculating a no-drift heading, you advise the captain to alter compass heading to 237°, which takes into account the change in variation.

**06:45 GCT**—The temperature has risen to +7°C. The sky is still overcast so you use the 07:00 DR position to fill in the Navigator's Flight Report and Radio Weather Report, using estimated wind.

**07:10 GCT** — The temperature is now +10°C. and the stars are starting to break through the clouds. It is possible to take a quick sight between cloud breaks. However, the horizon is rapidly clearing so you decide to wait a few minutes and take a good fix when the sky clears.

**07:20 GCT**—It is nearly clear, so you start shooting, as you are anxious to obtain a speed line in order to check fuel consumption. You are nearing the PN and a good fuel vs. distance check is necessary in order to determine definitely if you have sufficient fuel to continue to your destination.

This decision as to whether to continue to destination or to turn back is a very important one, and it should be based upon the most reliable information obtainable. Actually, the decision itself will be up to the captain, but he will have to rely largely upon the data with which you supply him. It behooves you, therefore, to keep a very accurate check on ground speed, winds encountered and fuel consumed, so that when it becomes time to decide there will be no cause for hesitation. The more complete and accurate your information, the easier will be the captain's decision, and the faster he can *act*. The more closely you approach the PN, the more critical becomes the time element. A delay of even a few minutes in acting can sometimes mean the difference between a safe arrival and a forced landing at sea.

So far your fuel consumption has not been excessive, but your proximity to the PN makes it important to have a final check. Accordingly, you work out the following sights:



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**SPICA**

GCT $07^h20^m07^s$

| | | | | |
|---|---|---|---|---|
| | | 332°18′ | | |
| | | 02′ | | |
| | | 159°27′ | | |
| GHA | = | 491°47′ | | |
| | | —360° | | |
| GHA | = | 131°47′ | | |
| **Assumed Long.** | = | 134°47′W | | |
| LHA | = | 3° E | | |
| **Assumed Lat.** | = | 27° N | | |
| Dec. | = | 10°52′S | | |

Lat. 27°N
Dec. 11°S
Opp. names

| | | |
|---|---|---|
| $H_s$ | = | 51°24′ |
| I. C. | = | —5′ |
| Ref. | = | 0′ |
| $H_o$ | = | 51°19′ |
| $H_c$ | = | 52°01.3′ |
| a | = | **42.3′ away** |
| $\Delta$d | = | 1.0 (x 8′ = 8.0′) |
| H | = | 51°53.3′ |
| $\Delta$d corr. | | +8.0′ |
| $H_c$ | = | 52°01.3′ |
| Az | = | **N 175.2°E** |

**ARCTURUS**

GCT $07^h23^m07^s$

| | | | | |
|---|---|---|---|---|
| | | 332°18′ | | |
| | | 0°47′ | | |
| | | 146°44′ | | |
| GHA | = | 479°49′ | | |
| | | —360° | | |
| GHA | = | 119°49′ | | |
| **Assumed Long.** | = | 134°49′W | | |
| LHA | = | 15° E | | |
| **Assumed Lat.** | = | 27° N | | |
| Dec. | = | 19°29′N | | |

Lat. 27°N
Dec. 19°30′N
Same name

| | | |
|---|---|---|
| $H_s$ | = | 74°10′ |
| I. C. | = | —5′ |
| Ref. | = | 0′ |
| $H_o$ | = | 74°05′ |
| $H_c$ | = | 74°19.2′ |
| a | = | **14.2′ away** |
| $\Delta$d | = | .52 (x 1′ = .5′) |
| H | = | 74°19.7′ |
| $\Delta$d corr. | | —.5′ |
| $H_c$ | = | 74°19.2′ |
| Az | = | **N 115.4°E** |

**REGULUS**

GCT $07^h26^m07^s$

| | | | | |
|---|---|---|---|---|
| | | 332°18′ | | |
| | | 1°32′ | | |
| | | 208°40′ | | |
| GHA | = | 542°30′ | | |
| | | —360° | | |
| GHA | = | 182°30′ | | |
| **Assumed Long.** | = | 134°30′W | | |
| LHA | = | 48° W | | |
| **Assumed Lat.** | = | 27° N | | |
| Dec. | = | 12°15′N | | |

Lat. 27°N
Dec. 12°N
Same name

| | | |
|---|---|---|
| $H_s$ | = | 43°09′ |
| I. C. | = | —5′ |
| Ref. | = | —1′ |
| $H_o$ | = | 43°03.0′ |
| $H_c$ | = | 42°45.8′ |
| a | = | **17.2′ toward** |
| $\Delta$d | = | .44 (x 15′ = 6.6′) |
| H | = | 42°39.2′ |
| $\Delta$d corr. | | +6.6′ |
| $H_c$ | = | 42°45.8′ |
| Az | = | **N 98.8°W** |



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Once again analyzing the fix (Figure 171), it becomes apparent that moving each of the lines slightly away from the body along the azimuth line will result in a point fix at the center of the triangle. The small triangle probably is due to a slight personal error in observation, as most of your sights are fairly close.

**07:50 GCT**—You find you are making good a track of 256° true from the last fix with wind 100°/18 knots, resulting in 3° right drift. Since the forecast has proved nearly accurate, you assume the wind will continue shifting around to the north. You decide, therefore, to fly a no-drift heading, parallel to the original course of 252°, estimating the same ground speed. You then advise the captain to alter compass heading to 236° which should keep the aircraft south of the course.

Advancing the fix to 08:00 GCT, you fill in the Navigator's Flight Report, Radio Weather Report and plot the actual position and fuel consumed on the Flight Graph. The graph indicates that you are using less gasoline than was estimated, and that it will be safe to continue to Honolulu.

**09:00 GCT**—You feel quite sure of your position, and since you have been busy the last hour catching up on all radio and weather reports, you take time out to cook up a can of soup and some coffee. You then fill in the 09:00 DR position on the Navigator's Flight Report.

**09:30 GCT**—It is time now to obtain another fix. Your previous fix included a good speed line, which afforded an accurate check on the distance flown—hence average ground speed—and the fuel-distance relationship. For the present, therefore, you are satisfied with the information you have regarding speed and distance. It now seems advisable to check the aircraft's position with reference to the course line, so you take another series of sights as follows:

**POLARIS**

GCT $09^h34^m07^s$

| | | |
|---|---|---|
| | | 4°53′ |
| | | 1°02′ |
| GHA ♈ | = | 5°55′ |
| | | +360°00′ |
| GHA ♈ | = | 365°55′W |
| DR Long. | = | 139°55′W |
| LHA ♈ | = | 226° W |

| | | |
|---|---|---|
| $H_s$ | = | 25°41′ |
| I. C. | = | —5′ |
| Ref. | = | —1′ |
| $H_o$ | = | 25°35′ |
| Corr. LHA ♈ | = | +57′ |
| **Latitude** | = | 26°32′N |

**ANTARES**

GCT $09^h37^m07^s$

| | | |
|---|---|---|
| | | 4°53′ |
| | | 1°47′ |
| | | 113°31′ |
| GHA | = | 120°11′ |
| **Assumed Long.** | = | 140°11′W |
| LHA | = | 20° E |
| **Assumed Lat.** | = | 26° N |
| Dec. | = | 26°18′S |

Lat. 26°N
Dec. 26°S
Opp. names

| | | |
|---|---|---|
| $H_s$ | = | 34°02′ |
| I. C. | = | —5′ |
| Ref. | = | —1′ |
| $H_o$ | = | 33°56′ |
| $H_c$ | = | 34°15.5′ |
| a | = | **19.5′ away** |
| $\Delta d$ | = | .93 (x 18′ = 16.7′) |
| H | = | 34°32.2′ |
| $\Delta d$ corr. | | —16.7′ |
| $H_c$ | = | 34°15.5′ |
| Az | = | **N 158.1°E** |



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**SPICA**

| | | | | | | |
|---|---|---|---|---|---|---|
| GCT $09^h40^m07^s$ | | | | Hs | = | 44°36′ |
| | | 7°23′ | | I. C. | = | —5′ |
| | | 02′ | | Ref. | = | —1′ |
| | | 159°27′ | | Ho | = | 44°30.0′ |
| GHA | = | 166°52′ | | Hc | = | 44°44.1′ |
| **Assumed Long.** | = | 139°52′W | | a | = | **13.9′ away** |
| LHA | = | 27° W | Lat. 26°N<br>Dec. 11°S<br>Opp. names | Δd | = | .82 (x 8′ = 6.6′) |
| **Assumed Lat.** | = | 26° N | | H | = | 44°37.5′ |
| Dec. | = | 10°52′S | | Δd corr. | | +6.6′ |
| | | | | Hc | = | 44°44.1′ |
| | | | | Az | = | **N 141.2°W** |

Checking the track made good (Figure 171), you find the aircraft is still drifting 3° to the right; however, the ground speed has decreased to 126 knots and the wind has shifted around to 130°/07 knots. You then advance the fix to 10:00 GCT and fill out the Navigator's Flight Report, using wind found and track made good.

Since the aircraft is a little North of the track, you continue to hold the same heading but estimate the wind will continue shifting around gradually to the Northwest as forecast. Therefore, you establish a DR position for 11:00 GCT (Figure 172) using estimated wind of 300°/05 knots and course of 250°.

**11:40 GCT** — It is time to compute the ETA (Estimated Time of Arrival) and also to check your course for the estimated wind shift; accordingly, you proceed to take another series of sights.

**ANTARES**

| | | | | | | |
|---|---|---|---|---|---|---|
| GCT $11^h44^m07^s$ | | | | Hs | = | 38°18′ |
| | | 37°28′ | | I. C. | = | —5′ |
| | | 1°02′ | | Ref. | = | —1′ |
| | | 113°31′ | | Ho | = | 38°12′ |
| GHA | = | 152°01′ | | Hc | = | 38°07.3′ |
| **Assumed Long.** | = | 144°01′W | | a | = | **4.7′ toward** |
| LHA | = | 8° W | Lat. 25°N<br>Dec. 26°S<br>Opp. names | Δd | = | .99 (x 18′ = 17.8′) |
| **Assumed Lat.** | = | 25° N | | H | = | 38°25.1′ |
| Dec. | = | 26°18′S | | Δd corr. | | —17.8′ |
| | | | | Hc | = | 38°07.3′ |
| | | | | Az | = | **N 170.8°W** |

**VEGA**

| | | | | | | |
|---|---|---|---|---|---|---|
| GCT $11^h47^m07^s$ | | | | Hs | = | 65°51′ |
| | | 37°28′ | | I. C. | = | —5′ |
| | | 1°47′ | | Ref. | = | 0′ |
| | | 81°14′ | | Ho | = | 65°46.0′ |
| GHA | = | 120°29′ | | Hc | = | 65°32.7′ |
| **Assumed Long.** | = | 144°29′W | | a | = | **13.3′ toward** |
| LHA | = | 24° E | Lat. 25°N<br>Dec. 38°30′N<br>Same name | Δd | = | .45 (x 14′ = 6.3′) |
| **Assumed Lat.** | = | 25° N | | H | = | 65°39.0′ |
| Dec. | = | 38°44′N | | Δd corr. | | —6.3′ |
| | | | | Hc | = | 65°32.7′ |
| | | | | Az | = | **N 50°E** |



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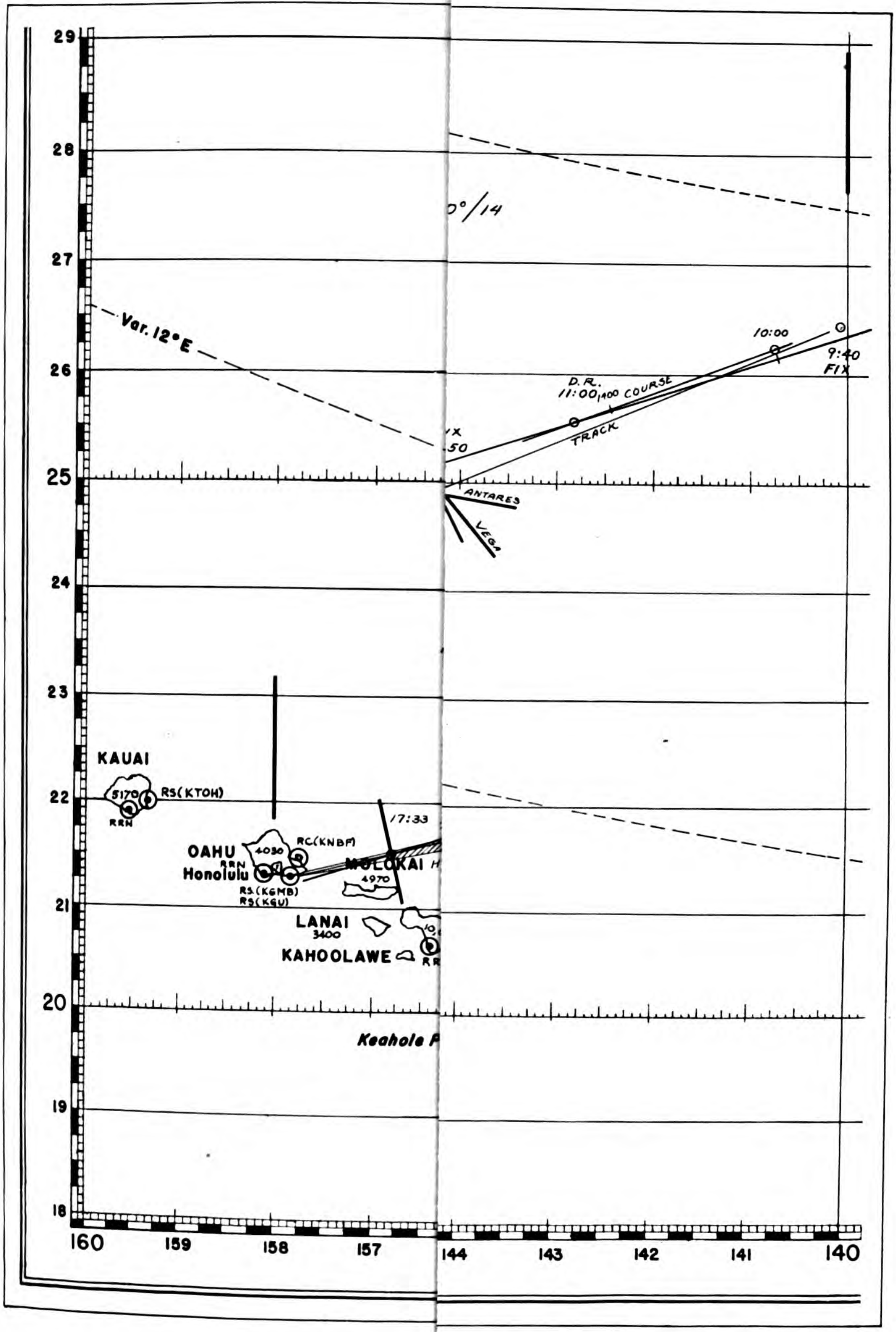

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**SPICA**

GCT 11h50m07s

| | | |
|---|---|---|
| | | 39°59′ |
| | | 02′ |
| | | 159°27′ |
| GHA | = | 199°28′ |
| **Assumed Long.** | = | 144°28′W |
| LHA | = | 55° W |
| **Assumed Lat.** | = | 25° N |
| Dec. | = | 10°52′S |

Lat. 25°N
Dec. 11°S
Opp. names

| | | |
|---|---|---|
| Hs | = | 25°27′ |
| I. C. | = | —5′ |
| Ref. | = | —2′ |
| Ho | = | 25°20.0′ |
| Hc | = | 25°31.2′ |
| a | = | **11.2′ away** |
| Δd | = | .57 (x 8′ = 4.5′) |
| H | = | 25°26.7′ |
| Δd corr. | | +4.5′ |
| Hc | = | 25°31.2′ |
| Az | = | **N 117°W** |

This fix (Figure 172) indicates that you have correctly estimated the wind shift; however, since you now wish to remain on course, you advance the fix to 12:00 GCT and lay out a new course to destination (254°). Estimating 5° left drift for additional wind shift, you then advise the captain to alter compass heading to 245°.

The Navigator's Flight Report and Radio Weather Report then are made out for 12:00 GCT, using wind and track made good.

To determine your ETA, you estimate that the ground speed probably will average about 125 knots, as the wind is expected to shift to 10°/07 knots. This means you have 6h18m more flying time ahead of you. Allowing 10 minutes for let-down procedure, you estimate the ETA to be 18:28 GCT.

Plotting your present actual position on the time vs. miles curve (Flight Graph) provides a good check on the ETA.

The 13:00 GCT report then is made out, using course to destination and estimated wind of 310°/14 knots as forecast.

**POLARIS**

GCT 13h24m07s

| | | |
|---|---|---|
| | | 62°32′ |
| | | 1°02′ |
| GHA ♈ | = | 63°34′ |
| | | +360° |
| GHA ♈ | = | 423°34′W |
| DR Long. | = | 147°34′W |
| LHA ♈ | = | 276°00′W |

| | | |
|---|---|---|
| Hs | = | 23°44′ |
| I. C. | = | —5′ |
| Ref. | = | —2′ |
| Ho | = | 23°37′ |
| Corr. LHA ♈ | = | +21′ |
| **Latitude** | = | 23°58′N |

**ANTARES**

GCT 13h27m07s

| | | |
|---|---|---|
| | | 62°32′ |
| | | 1°47′ |
| | | 113°31′ |
| GHA | = | 177°50′ |
| **Assumed Long.** | = | 147°50′W |
| LHA | = | 30° W |
| **Assumed Lat.** | = | 24° N |
| Dec. | = | 26°18′S |

Lat. 24°N
Dec. 26°S
Opp. names

| | | |
|---|---|---|
| Hs | = | 32°02′ |
| I. C. | = | —5′ |
| Ref. | = | —1′ |
| Ho | = | 31°56′ |
| Hc | = | 31°56.5′ |
| a | = | **0.5′ away** |
| Δd | = | .84 (x 18′ = 15.1′) |
| H | = | 32°11.6′ |
| Δd corr. | | —15.1′ |
| Hc | = | 31°56.5′ |
| Az | = | **N 148°W** |



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**ARCTURUS**

GCT $13^h30^m07^s$

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 65°03′ | | Hs | = | 30°52′ |
| | | 02′ | | I. C. | = | —5′ |
| | | 146°44′ | | Ref. | = | —1′ |
| | | | | Ho | = | 30°46′ |
| | | | | Hc | = | 30°53.2′ |
| GHA | = | 211°49′ | | a | = | **7.2′ away** |
| **Assumed Long.** | = | 147°49′W | | Δd | = | .29 (x 1′ = .3′) |
| LHA | = | 64° W | | H | = | 30°52.9′ |
| **Assumed Lat.** | = | 24° N | Lat. 24°N | Δd corr. | = | +.3′ |
| Dec. | = | 19°29′N | Dec. 19°30′N | Hc | = | 30°53.2′ |
| | | | Same name | Az | = | **N 81.0°W** |

**13:20 GCT**—To check the ETA and track, you take another series of sights as follows:

The 13:30 fix (Figure 172) proves that the wind is shifting to the North as forecast. Your ground speed has increased to 122 knots and your ETA is still 18:28 GCT.

Advancing this latest fix to 14:00 GCT, you again fill in the Navigator's Flight Report and Radio Weather Report.

**14:50 GCT**—Since the sky is starting to get lighter you decide to check the course and speed once more before daybreak, and so obtain the following sights:

**VEGA**

GCT $14^h52^m07^s$

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 85°06′ | | Hs | = | 69°11′ |
| | | 0°32′ | | I. C. | = | —5′ |
| | | 81°14′ | | Ref. | = | 0′ |
| | | | | Ho | = | 69°06.0′ |
| | | | | Hc | = | 69°11.0′ |
| GHA | = | 166°52′ | | a | = | **5.0′ away** |
| **Assumed Long.** | = | 150°52′W | | Δd | = | .69 (x 14′ = 9.7′) |
| LHA | = | 16° W | | H | = | 69°20.7′ |
| **Assumed Lat.** | = | 23° N | Lat. 23°N | Δd corr. | | —9.7′ |
| Dec. | = | 38°44′N | Dec. 38°30′N | Hc | = | 69°11.0′ |
| | | | Same name | Az | = | **N 37.7°W** |

**ANTARES**

GCT $14^h55^m07^s$

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 85°06′ | | Hs | = | 21°42′ |
| | | 1°17′ | | I. C. | = | —5′ |
| | | 113°31′ | | Ref. | = | —2′ |
| | | | | Ho | = | 21°35′ |
| | | | | Hc | = | 21°36.6′ |
| GHA | = | 199°54′ | | a | = | **1.6′ away** |
| **Assumed Long.** | = | 150°54′W | | Δd | = | .66 (x 18′ = 11.9′) |
| LHA | = | 49° W | | H | = | 21°48.5′ |
| **Assumed Lat.** | = | 23° N | Lat. 23°N | Δd corr. | | —11.9′ |
| Dec. | = | 26°18′S | Dec. 26°S | Hc | = | 21°36.6′ |
| | | | Opp. names | Az | = | **N 133.1°W** |



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Checking the track made good, you find the wind has increased so that you are now making a ground speed of 128 knots with 7° left drift.

Advancing the fix to 15:00, and before filling in Navigator's Flight Report, you first fix your present position as of 15:20 GCT and establish a new course to Honolulu. You then advise the captain to alter compass heading to 249° in order to make 256° true.

**15:30 GCT** — The sun is starting to rise, and although you have felt you could hardly hold your eyes open for the last couple of hours, you now feel exhilarated, your energy renewed. You anxiously anticipate seeing the peaks of the Islands break through the clouds.

Until the sun is higher, it will not be practical to take sights, so you establish a DR position for 16:00 and fill in the Navigator's Flight Report, using present course and last known wind.

**16:20 GCT**—You turn on the radio compass and listen to the Honolulu radio range. Hearing a steady dash, with an occasional weak dot-dash (A), proves you are right on course. You relax, feeling satisfied that you have done a nice job of navigation.

**17:00 GCT**—The sun is high enough now for a sight, so you take a shot to check the speed (see below).

The sun line (Figure 172) indicates that you still are making 128 knots.

**17:20 GCT**—There are clouds obscuring Maui, but you are sure of your position now and the radio range proves you are well clear of the mountain peaks on Maui and Molokai. You tell the captain that if he will start letting down through the clouds, he will see the east end of Molokai abeam at 17:35.

The captain follows your suggestion and sure enough you see the shore line. However, the increased speed of letting down puts Molokai abeam at 17:33, and the crew razz you for being two minutes off. Nonetheless, you know from their smiles that they would trust your navigation anywhere.

For you the flight is as good as over. You start packing your equipment and sit back and relax while the captain brings in the PBY contact and lands on the bay at Honolulu.

The navigator shouldn't always relax, however, upon sighting land. Quite often he can be of immense assistance to the captain by keeping a close check on the landmarks passed and by computing the best headings to the air base. This is especially true in bad weather when the captain must give all of his attention to flying.

**18:29 GCT**—On water. Finish filling out the Navigator's Flight Report.

Your trip to Honolulu is over.

**SUN**

GCT $17^h00^m07^s$

| | | |
|---|---|---|
| | | 75°50′ |
| | | **02′** |
| GHA | = | 75°52′ |
| **Assumed Long.** | = | 154°52′W |
| LHA | = | 79° E |
| **Assumed Lat.** | = | 22° N |
| Dec. | = | 16°08′N |

Lat. 22°N
Dec. 16°N
Same name

| | | |
|---|---|---|
| $H_s$ | = | 15°28′ |
| I. C. | = | —5′ |
| Ref. | = | —3′ |
| $H_o$ | = | 15°20′ |
| $H_c$ | = | 15°54.3′ |
| a | = | **34.3′ away** |
| $\Delta$d | = | .32 (x 8′ = 2.6′) |
| H | = | 15°51.7′ |
| $\Delta$d corr. | | +2.6′ |
| $H_c$ | = | 15°54.3′ |
| Az | = | **N 78.8°E** |



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## PROBLEM WORK NO. 32

### PBY FLIGHT FROM SAN DIEGO TO HONOLULU

MAY 5, 1943

**True Course = 253° Total Distance = 2,290 Nautical Miles**

I.A.S. = 92 knots, calibration correction +5 knots.
Fuel aboard at start = 1875 U. S. gallons. Average fuel consumption = 75 g.p.h., during climb = 100 g.p.h.
Flight altitude = 8000′. Temperature +10°C for total trip.

(Follow all procedures in order, thus simulating actual flight. Plot fixes on a small scale chart. Keep running account of flight by filling in flight plan for each hour before proceeding with next fix. Using forecast wind, establish first heading. Do not alter course unless indicated. Deviation is 0°.)

FORECAST WIND FOR 8000′

| | | |
|---|---|---|
| ZONE 1 | SAN DIEGO to 120° W Long. | 315° / 20 knots |
| ZONE 2 | 120° W to 130° W | 315° / 20 knots |
| ZONE 3 | 130° W to 140° W | 135° / 20 knots |
| ZONE 4 | 140° W to 150° W | 20° / 20 knots |
| ZONE 5 | 150° W to HONOLULU | 45° / 15 knots |

00:31 GCT off water, compass heading = 246°. (Climb 29 min. at an I.A.S. of 100 knots.)

00:37 Relative radio bearing taken of KFSD, San Diego = 171°. Magnetic heading = 247° (at the instant bearing was taken). Mercator correction = —1°.

| No. | STAR SIGHTS TAKEN EN ROUTE—INDEX CORRECTION = 0° | | |
|---|---|---|---|
| 1 | DUBHE GCT = 03:27:00 $H_s$ = 57° 06′ | BETELGEUX GCT = 03:32:00 $H_s$ = 26° 32′ | SIRIUS GCT = 03:37:00 $H_s$ = 21° 18′ |
| 2 | PROCYON GCT = 05:00:00 $H_s$ = 31° 44′ | DUBHE GCT = 04:56:00 $H_s$ = 57° 16′ | POLLUX GCT = 05:05:00 $H_s$ = 41° 15′ |
| 3 | DUBHE GCT = 07:14:00 $H_s$ = 49° 12′ | POLLUX GCT = 07:00:00 $H_s$ = 20° 06′ | SPICA GCT = 07:05:00 $H_s$ = 50° 49′ |
| 4 | REGULUS GCT = 09:00:00 $H_s$ = 22° 21′ | SPICA GCT = 09:04:00 $H_s$ = 46° 30′ | DUBHE GCT = 09:09:00 $H_s$ = 37° 42′ |
| | 09:50 GCT Alter course to intercept destination. | | |
| 5 | ANTARES GCT = 11:55:00 $H_s$ = 37° 35′ | ARCTURUS GCT = 12:00:00 $H_s$ = 46° 42′ | |
| 6 | ALKAID GCT = 13:04:00 $H_s$ = 32° 48′ | ARCTURUS GCT = 13:07:30 $H_s$ = 33° 38′ | ANTARES GCT = 13:12:00 $H_s$ = 32° 04′ |
| 7 | ANTARES GCT = 14:04:00 $H_s$ = 26° 46′ | ARCTURUS GCT = 14:00:00 $H_s$ = 23° 32′ | |

16:34 GCT Radio bearing KMZA = 296°, magnetic heading = 263°.
16:36 GCT Radio bearing KNBF = 333°, magnetic heading = 263°.
16:45 GCT ALTER COURSE TO INTERCEPT DESTINATION.



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**NAVIGATOR'S FLIGHT REPORT**

TRIP NO. .................... DATE .................... CAPTAIN .................... CO-PILOT ....................

ORIGIN .................... DESTINATION .................... NAVIGATOR .................... RADIOMAN ....................

PLANE NO. .................... TYPE .................... RADIO CALL .................... ENGINEER ....................

| TIME | POSITION | | | AIR SPEED | | | ALTITUDE | Temp. | Course | DRIFT | True | VARIATION | DEVIATION | Comp | WIND | | GROUND SPEED | TIME ELAPSED | DISTANCE | | GASOLINE | | | WEIGHT | M.P. | R.P.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G.C.T. | Lat. | Long. | TYPE | IAS | CAS | TAS | | °C. | or Track | | Head | | | Head | Dir. | Vel. | | | Flown | To Go | Rate Cons. | Used | Remain | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
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# APPENDIX



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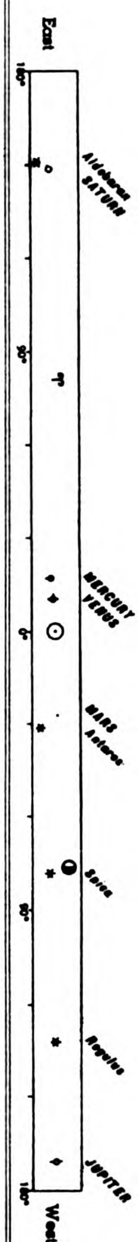
## GREENWICH A. M. 1943 JANUARY 1 (FRIDAY)

| GCT | ☉ SUN GHA | ☉ SUN Dec. | ♈ GHA | MARS 1.7 GHA | MARS 1.7 Dec. | JUPITER −2.2 GHA | JUPITER −2.2 Dec. | SATURN 0.0 GHA | SATURN 0.0 Dec. | ◑ MOON GHA | ◑ MOON Dec. | ☾ Par. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | |
| 0 00 | 179 14 | S23 05 | 99 46 | 209 51 | S22 16 | 346 25 | N21 59 | 34 31 | N19 36 | 255 25 | S 5 25 | |
| 10 | 181 44 | | 102 17 | 212 21 | | 348 56 | | 37 01 | | 257 50 | 27 | |
| 20 | 184 14 | | 104 47 | 214 51 | | 351 26 | | 39 31 | | 260 15 | 29 | |
| 30 | 186 43 | · · | 107 18 | 217 21 | · · | 353 57 | · · | 42 02 | · · | 262 40 | · 30 | Alt. Corr. |
| 40 | 189 13 | | 109 48 | 219 51 | | 356 27 | | 44 32 | | 265 05 | 32 | |
| 50 | 191 43 | | 112 18 | 222 21 | | 358 57 | | 47 03 | | 267 30 | 34 | ° + ′ |
| 1 00 | 194 13 | S23 05 | 114 49 | 224 51 | S22 16 | 1 28 | N21 59 | 49 33 | N19 36 | 269 55 | S 5 36 | |
| 10 | 196 43 | | 117 19 | 227 21 | | 3 58 | | 52 04 | | 272 20 | 38 | 0 59 |
| 20 | 199 13 | | 119 50 | 229 51 | | 6 29 | | 54 34 | | 274 45 | 39 | 8 58 |
| 30 | 201 43 | · · | 122 20 | 232 21 | · · | 8 59 | · · | 57 05 | · · | 277 10 | · 41 | 13 57 |
| 40 | 204 13 | | 124 50 | 234 52 | | 11 30 | | 59 35 | | 279 35 | 43 | 17 56 |
| 50 | 206 43 | | 127 21 | 237 22 | | 14 00 | | 62 05 | | 282 01 | 45 | 20 55 |
| 2 00 | 209 13 | S23 05 | 129 51 | 239 52 | S22 16 | 16 31 | N21 59 | 64 36 | N19 36 | 284 26 | S 5 47 | 23 54 |
| 10 | 211 43 | | 132 22 | 242 22 | | 19 01 | | 67 06 | | 286 51 | 48 | 25 53 |
| 20 | 214 13 | | 134 52 | 244 52 | | 21 32 | | 69 37 | | 289 16 | 50 | 27 52 |
| 30 | 216 43 | · · | 137 23 | 247 22 | · · | 24 02 | · · | 72 07 | · · | 291 41 | · 52 | 29 51 |
| 40 | 219 13 | | 139 53 | 249 52 | | 26 33 | | 74 38 | | 294 06 | 54 | 31 50 |
| 50 | 221 43 | | 142 23 | 252 22 | | 29 03 | | 77 08 | | 296 31 | 55 | 33 49 |
| | | | | | | | | | | | | 35 48 |
| 3 00 | 224 13 | S23 05 | 144 54 | 254 52 | S22 17 | 31 34 | N21 59 | 79 38 | N19 36 | 298 56 | S 5 57 | 36 47 |
| 10 | 226 43 | | 147 24 | 257 22 | | 34 04 | | 82 09 | | 301 21 | 5 59 | 38 46 |
| 20 | 229 13 | | 149 55 | 259 53 | | 36 34 | | 84 39 | | 303 46 | 6 01 | 40 45 |
| 30 | 231 43 | · · | 152 25 | 262 23 | · · | 39 05 | · · | 87 10 | · · | 306 11 | · 03 | 41 44 |
| 40 | 234 13 | | 154 55 | 264 53 | | 41 35 | | 89 40 | | 308 36 | 04 | 43 43 |
| 50 | 236 42 | | 157 26 | 267 23 | | 44 06 | | 92 11 | | 311 01 | 06 | 44 42 |
| 4 00 | 239 12 | S23 05 | 159 56 | 269 53 | S22 17 | 46 36 | N21 59 | 94 41 | N19 36 | 313 26 | S 6 08 | 45 41 |
| 10 | 241 42 | | 162 27 | 272 23 | | 49 07 | | 97 12 | | 315 51 | 10 | 47 40 |
| 20 | 244 12 | | 164 57 | 274 53 | | 51 37 | | 99 42 | | 318 16 | 11 | 48 39 |
| 30 | 246 42 | · · | 167 27 | 277 23 | · · | 54 08 | · · | 102 12 | · · | 320 42 | · 13 | 49 38 |
| 40 | 249 12 | | 169 58 | 279 53 | | 56 38 | | 104 43 | | 323 07 | 15 | 51 37 |
| 50 | 251 42 | | 172 28 | 282 23 | | 59 09 | | 107 13 | | 325 32 | 17 | 52 36 |
| 5 00 | 254 12 | S23 04 | 174 59 | 284 53 | S22 17 | 61 39 | N21 59 | 109 44 | N19 36 | 327 57 | S 6 19 | 53 35 |
| 10 | 256 42 | | 177 29 | 287 24 | | 64 10 | | 112 14 | | 330 22 | 20 | 54 34 |
| 20 | 259 12 | | 180 00 | 289 54 | | 66 40 | | 114 45 | | 332 47 | 22 | 56 33 |
| 30 | 261 42 | · · | 182 30 | 292 24 | · · | 69 11 | · · | 117 15 | · · | 335 12 | · 24 | 57 32 |
| 40 | 264 12 | | 185 00 | 294 54 | | 71 41 | | 119 45 | | 337 37 | 26 | 58 31 |
| 50 | 266 42 | | 187 31 | 297 24 | | 74 12 | | 122 16 | | 340 02 | 27 | 59 30 |
| | | | | | | | | | | | | 60 29 |
| 6 00 | 269 12 | S23 04 | 190 01 | 299 54 | S22 18 | 76 42 | N21 59 | 124 46 | N19 36 | 342 27 | S 6 29 | 61 28 |
| 10 | 271 42 | | 192 32 | 302 24 | | 79 12 | | 127 17 | | 344 52 | 31 | 62 27 |
| 20 | 274 12 | | 195 02 | 304 54 | | 81 43 | | 129 47 | | 347 17 | 33 | 64 26 |
| 30 | 276 42 | · · | 197 32 | 307 24 | · · | 84 13 | · · | 132 18 | · · | 349 42 | · 34 | 65 25 |
| 40 | 279 12 | | 200 03 | 309 54 | | 86 44 | | 134 48 | | 352 07 | 36 | 66 24 |
| 50 | 281 42 | | 202 33 | 312 25 | | 89 14 | | 137 19 | | 354 32 | 38 | 67 23 |
| 7 00 | 284 12 | S23 04 | 205 04 | 314 55 | S22 18 | 91 45 | N21 59 | 139 49 | N19 36 | 356 57 | S 6 40 | 68 22 |
| 10 | 286 42 | | 207 34 | 317 25 | | 94 15 | | 142 19 | | 359 22 | 41 | 69 21 |
| 20 | 289 11 | | 210 04 | 319 55 | | 96 46 | | 144 50 | | 1 47 | 43 | 70 20 |
| 30 | 291 41 | · · | 212 35 | 322 25 | · · | 99 16 | · · | 147 20 | · · | 4 12 | · 45 | 71 19 |
| 40 | 294 11 | | 215 05 | 324 55 | | 101 47 | | 149 51 | | 6 37 | 47 | 72 18 |
| 50 | 296 41 | | 217 36 | 327 25 | | 104 17 | | 152 21 | | 9 02 | 49 | 73 17 |
| 8 00 | 299 11 | S23 04 | 220 06 | 329 55 | S22 18 | 106 48 | N21 59 | 154 52 | N19 36 | 11 27 | S 6 50 | 74 16 |
| 10 | 301 41 | | 222 37 | 332 25 | | 109 18 | | 157 22 | | 13 52 | 52 | 75 15 |
| 20 | 304 11 | | 225 07 | 334 55 | | 111 49 | | 159 52 | | 16 17 | 54 | 76 14 |
| 30 | 306 41 | · · | 227 37 | 337 25 | · · | 114 19 | · · | 162 23 | · · | 18 42 | · 56 | 77 13 |
| 40 | 309 11 | | 230 08 | 339 56 | | 116 49 | | 164 53 | | 21 07 | 57 | 78 12 |
| 50 | 311 41 | | 232 38 | 342 26 | | 119 20 | | 167 24 | | 23 32 | 6 59 | 79 11 |
| | | | | | | | | | | | | 80 10 |
| 9 00 | 314 11 | S23 04 | 235 09 | 344 56 | S22 18 | 121 50 | N21 59 | 169 54 | N19 36 | 25 57 | S 7 01 | |
| 10 | 316 41 | | 237 39 | 347 26 | | 124 21 | | 172 25 | | 28 22 | 03 | |
| 20 | 319 11 | | 240 09 | 349 56 | | 126 51 | | 174 55 | | 30 47 | 04 | SD, ☉ |
| 30 | 321 41 | · · | 242 40 | 352 26 | · · | 129 22 | · · | 177 26 | · · | 33 12 | · 06 | |
| 40 | 324 11 | | 245 10 | 354 56 | | 131 52 | | 179 56 | | 35 37 | 08 | 16 |
| 50 | 326 41 | | 247 41 | 357 26 | | 134 23 | | 182 26 | | 38 02 | 10 | |
| 10 00 | 329 11 | S23 03 | 250 11 | 359 56 | S22 19 | 136 53 | N21 59 | 184 57 | N19 36 | 40 27 | S 7 11 | SD, ☾ |
| 10 | 331 41 | | 252 41 | 2 26 | | 139 24 | | 187 27 | | 42 52 | 13 | |
| 20 | 334 11 | | 255 12 | 4 57 | | 141 54 | | 189 58 | | 45 17 | 15 | 16 |
| 30 | 336 41 | · · | 257 42 | 7 27 | · · | 144 25 | · · | 192 28 | · · | 47 42 | · 17 | |
| 40 | 339 10 | | 260 13 | 9 57 | | 146 55 | | 194 59 | | 50 07 | 18 | Corr. |
| 50 | 341 40 | | 262 43 | 12 27 | | 149 26 | | 197 29 | | 52 32 | 20 | HA ☾ |
| 11 00 | 344 10 | S23 03 | 265 13 | 14 57 | S22 19 | 151 56 | N21 59 | 199 59 | N19 36 | 54 57 | S 7 22 | |
| 10 | 346 40 | | 267 44 | 17 27 | | 154 26 | | 202 30 | | 57 22 | 24 | Int. Corr. |
| 20 | 349 10 | | 270 14 | 19 57 | | 156 57 | | 205 00 | | 59 47 | 25 | |
| 30 | 351 40 | · · | 272 45 | 22 27 | · · | 159 27 | · · | 207 31 | · · | 62 12 | · 27 | m ′ |
| 40 | 354 10 | | 275 15 | 24 57 | | 161 58 | | 210 01 | | 64 37 | 29 | 0 0 |
| 50 | 356 40 | | 277 46 | 27 27 | | 164 28 | | 212 32 | | 67 02 | 31 | 10 |
| 12 00 | 359 10 | S23 03 | 280 16 | 29 57 | S22 19 | 166 59 | N21 59 | 215 02 | N19 36 | 69 27 | S 7 32 | |



# GREENWICH P. M. 1943 JANUARY 1 (FRIDAY)

| GCT | ☉ SUN GHA | SUN Dec. | ♈ GHA | MARS 1.7 GHA | MARS Dec. | JUPITER −2.2 GHA | JUPITER Dec. | SATURN 0.0 GHA | SATURN Dec. | ◑ MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 00 | 359 10 | S23 03 | 280 16 | 29 57 | S22 19 | 166 59 | N21 59 | 215 02 | N19 36 | 69 27 | S 7 32 |
| 10 | 1 40 | | 282 46 | 32 28 | | 169 29 | | 217 33 | | 71 51 | 34 |
| 20 | 4 10 | | 285 17 | 34 58 | | 172 00 | | 220 03 | | 74 16 | 36 |
| 30 | 6 40 | . . | 287 47 | 37 28 | . . | 174 30 | . . | 222 33 | . . | 76 41 | . 38 |
| 40 | 9 10 | | 290 18 | 39 58 | | 177 01 | | 225 04 | | 79 06 | 39 |
| 50 | 11 40 | | 292 48 | 42 28 | | 179 31 | | 227 34 | | 81 31 | 41 |
| 13 00 | 14 10 | S23 03 | 295 18 | 44 58 | S22 19 | 182 02 | N21 59 | 230 05 | N19 36 | 83 56 | S 7 43 |
| 10 | 16 40 | | 297 49 | 47 28 | | 184 32 | | 232 35 | | 86 21 | 45 |
| 20 | 19 10 | | 300 19 | 49 58 | | 187 03 | | 235 06 | | 88 46 | 46 |
| 30 | 21 40 | . . | 302 50 | 52 28 | . . | 189 33 | . . | 237 36 | . . | 91 11 | . 48 |
| 40 | 24 10 | | 305 20 | 54 58 | | 192 04 | | 240 06 | | 93 36 | 50 |
| 50 | 26 40 | | 307 50 | 57 28 | | 194 34 | | 242 37 | | 96 01 | 52 |
| 14 00 | 29 09 | S23 03 | 310 21 | 59 59 | S22 20 | 197 04 | N21 59 | 245 07 | N19 36 | 98 26 | S 7 53 |
| 10 | 31 39 | | 312 51 | 62 29 | | 199 35 | | 247 38 | | 100 51 | 55 |
| 20 | 34 09 | | 315 22 | 64 59 | | 202 05 | | 250 08 | | 103 16 | 57 |
| 30 | 36 39 | . . | 317 52 | 67 29 | . . | 204 36 | . . | 252 39 | . . | 105 41 | . 7 59 |
| 40 | 39 09 | | 320 23 | 69 59 | | 207 06 | | 255 09 | | 108 06 | 8 00 |
| 50 | 41 39 | | 322 53 | 72 29 | | 209 37 | | 257 39 | | 110 30 | 02 |
| 15 00 | 44 09 | S23 02 | 325 23 | 74 59 | S22 20 | 212 07 | N21 59 | 260 10 | N19 36 | 112 55 | S 8 04 |
| 10 | 46 39 | | 327 54 | 77 29 | | 214 38 | | 262 40 | | 115 20 | 05 |
| 20 | 49 09 | | 330 24 | 79 59 | | 217 08 | | 265 11 | | 117 45 | 07 |
| 30 | 51 39 | . . | 332 55 | 82 29 | . . | 219 39 | . . | 267 41 | . . | 120 10 | . 09 |
| 40 | 54 09 | | 335 25 | 85 00 | | 222 09 | | 270 12 | | 122 35 | 11 |
| 50 | 56 39 | | 337 55 | 87 30 | | 224 40 | | 272 42 | | 125 00 | 12 |
| 16 00 | 59 09 | S23 02 | 340 26 | 90 00 | S22 20 | 227 10 | N21 59 | 275 13 | N19 36 | 127 25 | S 8 14 |
| 10 | 61 39 | | 342 56 | 92 30 | | 229 41 | | 277 43 | | 129 50 | 16 |
| 20 | 64 09 | | 345 27 | 95 00 | | 232 11 | | 280 13 | | 132 15 | 18 |
| 30 | 66 39 | . . | 347 57 | 97 30 | . . | 234 41 | . . | 282 44 | . . | 134 40 | . 19 |
| 40 | 69 09 | | 350 27 | 100 00 | | 237 12 | | 285 14 | | 137 04 | 21 |
| 50 | 71 39 | | 352 58 | 102 30 | | 239 42 | | 287 45 | | 139 29 | 23 |
| 17 00 | 74 09 | S23 02 | 355 28 | 105 00 | S22 20 | 242 13 | N21 59 | 290 15 | N19 36 | 141 54 | S 8 24 |
| 10 | 76 39 | | 357 59 | 107 30 | | 244 43 | | 292 46 | | 144 19 | 26 |
| 20 | 79 08 | | 0 29 | 110 00 | | 247 14 | | 295 16 | | 146 44 | 28 |
| 30 | 81 38 | . . | 3 00 | 112 31 | . . | 249 44 | . . | 297 46 | . . | 149 09 | . 30 |
| 40 | 84 08 | | 5 30 | 115 01 | | 252 15 | | 300 17 | | 151 34 | 31 |
| 50 | 86 38 | | 8 00 | 117 31 | | 254 45 | | 302 47 | | 153 59 | 33 |
| 18 00 | 89 08 | S23 02 | 10 31 | 120 01 | S22 21 | 257 16 | N22 00 | 305 18 | N19 36 | 156 24 | S 8 35 |
| 10 | 91 38 | | 13 01 | 122 31 | | 259 46 | | 307 48 | | 158 48 | 36 |
| 20 | 94 08 | | 15 32 | 125 01 | | 262 17 | | 310 19 | | 161 13 | 38 |
| 30 | 96 38 | . . | 18 02 | 127 31 | . . | 264 47 | . . | 312 49 | . . | 163 38 | . 40 |
| 40 | 99 08 | | 20 32 | 130 01 | | 267 18 | | 315 20 | | 166 03 | 42 |
| 50 | 101 38 | | 23 03 | 132 31 | | 269 48 | | 317 50 | | 168 28 | 43 |
| 19 00 | 104 08 | S23 02 | 25 33 | 135 01 | S22 21 | 272 18 | N22 00 | 320 20 | N19 36 | 170 53 | S 8 45 |
| 10 | 106 38 | | 28 04 | 137 32 | | 274 49 | | 322 51 | | 173 18 | 47 |
| 20 | 109 08 | | 30 34 | 140 02 | | 277 19 | | 325 21 | | 175 43 | 48 |
| 30 | 111 38 | . . | 33 04 | 142 32 | . . | 279 50 | . . | 327 52 | . . | 178 07 | . 50 |
| 40 | 114 08 | | 35 35 | 145 02 | | 282 20 | | 330 22 | | 180 32 | 52 |
| 50 | 116 38 | | 38 05 | 147 32 | | 284 51 | | 332 53 | | 182 57 | 54 |
| 20 00 | 119 08 | S23 01 | 40 36 | 150 02 | S22 21 | 287 21 | N22 00 | 335 23 | N19 36 | 185 22 | S 8 55 |
| 10 | 121 38 | | 43 06 | 152 32 | | 289 52 | | 337 53 | | 187 47 | 57 |
| 20 | 124 08 | | 45 36 | 155 02 | | 292 22 | | 340 24 | | 190 12 | 8 59 |
| 30 | 126 38 | . . | 48 07 | 157 32 | . . | 294 53 | . . | 342 54 | . . | 192 36 | . 9 00 |
| 40 | 129 08 | | 50 37 | 160 02 | | 297 23 | | 345 25 | | 195 01 | 02 |
| 50 | 131 37 | | 53 08 | 162 32 | | 299 54 | | 347 55 | | 197 26 | 04 |
| 21 00 | 134 07 | S23 01 | 55 38 | 165 03 | S22 22 | 302 24 | N22 00 | 350 26 | N19 36 | 199 51 | S 9 06 |
| 10 | 136 37 | | 58 09 | 167 33 | | 304 55 | | 352 56 | | 202 16 | 07 |
| 20 | 139 07 | | 60 39 | 170 03 | | 307 25 | | 355 27 | | 204 41 | 09 |
| 30 | 141 37 | . . | 63 09 | 172 33 | . . | 309 56 | . . | 357 57 | . . | 207 06 | . 11 |
| 40 | 144 07 | | 65 40 | 175 03 | | 312 26 | | 0 27 | | 209 30 | 12 |
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| 22 00 | 149 07 | S23 01 | 70 41 | 180 03 | S22 22 | 317 27 | N22 00 | 5 28 | N19 36 | 214 20 | S 9 16 |
| 10 | 151 37 | | 73 11 | 182 33 | | 319 57 | | 7 59 | | 216 45 | 17 |
| 20 | 154 07 | | 75 41 | 185 03 | | 322 28 | | 10 29 | | 219 10 | 19 |
| 30 | 156 37 | . . | 78 12 | 187 33 | . . | 324 58 | . . | 13 00 | . . | 221 35 | . 21 |
| 40 | 159 07 | | 80 42 | 190 04 | | 327 29 | | 15 30 | | 223 59 | 22 |
| 50 | 161 37 | | 83 13 | 192 34 | | 329 59 | | 18 00 | | 226 24 | 24 |
| 23 00 | 164 07 | S23 01 | 85 43 | 195 04 | S22 22 | 332 30 | N22 00 | 20 31 | N19 36 | 228 49 | S 9 26 |
| 10 | 166 37 | | 88 13 | 197 34 | | 335 00 | | 23 01 | | 231 14 | 27 |
| 20 | 169 07 | | 90 44 | 200 04 | | 337 31 | | 25 32 | | 233 39 | 29 |
| 30 | 171 37 | . . | 93 14 | 202 34 | . . | 340 01 | . . | 28 02 | . . | 236 03 | . 31 |
| 40 | 174 07 | | 95 45 | 205 04 | | 342 32 | | 30 33 | | 238 28 | 33 |
| 50 | 176 37 | | 98 15 | 207 34 | | 345 02 | | 33 03 | | 240 53 | 34 |
| 24 00 | 179 07 | S23 01 | 100 46 | 210 04 | S22 22 | 347 33 | N22 00 | 35 34 | N19 36 | 243 18 | S 9 36 |

| Lat. | Sunrise | Twil. | Moonrise | Diff. |
|---|---|---|---|---|
| N | | | | |
| ° | h m | m | h m | m |
| 60 | 9 03 | 57 | 1 43 | 83 |
| 58 | 8 46 | 51 | 39 | 81 |
| 56 | 32 | 47 | 36 | 79 |
| 54 | 19 | 43 | 34 | 76 |
| 52 | 8 08 | 40 | 31 | 75 |
| 50 | 7 59 | 38 | 29 | 73 |
| 45 | 38 | 34 | 24 | 70 |
| 40 | 22 | 31 | 21 | 66 |
| 35 | 7 08 | 28 | 17 | 64 |
| 30 | 6 56 | 26 | 14 | 61 |
| 20 | 35 | 24 | 09 | 57 |
| 10 | 6 17 | 23 | 05 | 53 |
| 0 | 5 59 | 22 | 1 01 | 50 |
| 10 | 5 43 | 23 | 0 57 | 47 |
| 20 | 24 | 25 | 52 | 44 |
| 30 | 5 02 | 27 | 48 | 40 |
| 35 | 4 49 | 29 | 45 | 38 |
| 40 | 34 | 32 | 42 | 35 |
| 45 | 4 17 | 36 | 38 | 32 |
| 50 | 3 55 | 43 | 34 | 29 |
| 52 | 44 | 48 | 32 | 27 |
| 54 | 32 | 53 | 30 | 25 |
| 56 | 18 | 61 | 27 | 24 |
| 58 | 3 02 | 72 | 25 | 21 |
| 60 | 2 42 | 95 | 0 22 | 18 |
| S | | | | |

| Lat. | Sunset | Twil. | Moonset | Diff. |
|---|---|---|---|---|
| N | | | | |
| ° | h m | m | h m | m |
| 60 | 15 04 | 57 | 12 28 | 20 |
| 58 | 21 | 51 | 32 | 23 |
| 56 | 35 | 47 | 36 | 25 |
| 54 | 48 | 43 | 40 | 27 |
| 52 | 15 58 | 40 | 43 | 29 |
| 50 | 16 08 | 38 | 46 | 30 |
| 45 | 28 | 34 | 52 | 34 |
| 40 | 45 | 31 | 12 57 | 37 |
| 35 | 16 59 | 28 | 13 02 | 39 |
| 30 | 17 11 | 26 | 06 | 42 |
| 20 | 32 | 24 | 13 | 45 |
| 10 | 17 50 | 22 | 19 | 49 |
| 0 | 18 07 | 22 | 24 | 52 |
| 10 | 25 | 23 | 30 | 55 |
| 20 | 18 43 | 25 | 36 | 59 |
| 30 | 19 05 | 27 | 43 | 63 |
| 35 | 18 | 29 | 47 | 65 |
| 40 | 33 | 32 | 52 | 67 |
| 45 | 19 50 | 37 | 13 57 | 70 |
| 50 | 20 12 | 44 | 14 04 | 73 |
| 52 | 23 | 49 | 06 | 76 |
| 54 | 35 | 54 | 10 | 77 |
| 56 | 20 49 | 61 | 13 | 80 |
| 58 | 21 05 | 73 | 17 | 82 |
| 60 | 21 25 | 96 | 14 22 | 85 |
| S | | | | |



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# GREENWICH A. M. 1943 MAY 1 (SATURDAY)

| GCT h m | ☉ SUN GHA ° ′ | SUN Dec. ° ′ | ♈ GHA ° ′ | VENUS -3.5 GHA ° ′ | VENUS Dec. ° ′ | MARS 1.1 GHA ° ′ | MARS Dec. ° ′ | JUPITER -1.6 GHA ° ′ | JUPITER Dec ° ′ | ◐ MOON GHA ° ′ | MOON Dec. ° ′ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 00 | 180 42 | N14 41 | 218 03 | 141 26 | N24 45 | 235 43 | S 9 09 | 107 34 | N22 31 | 219 19 | S 3 45 |
| 10 | 183 12 | | 220 33 | 143 56 | | 238 13 | | 110 04 | | 221 44 | 43 |
| 20 | 185 42 | | 223 04 | 146 26 | | 240 43 | | 112 35 | | 224 09 | 41 |
| 30 | 188 12 | · · | 225 34 | 148 56 | · · | 243 13 | · · | 115 05 | · · | 226 34 | · 39 |
| 40 | 190 42 | | 228 05 | 151 26 | | 245 43 | | 117 35 | | 228 59 | 37 |
| 50 | 193 12 | | 230 35 | 153 55 | | 248 13 | | 120 06 | | 231 24 | 35 |
| 1 00 | 195 42 | N14 45 | 233 05 | 156 25 | N24 45 | 250 43 | S 9 09 | 122 36 | N22 31 | 233 49 | S 3 33 |
| 10 | 198 12 | | 235 36 | 158 55 | | 253 13 | | 125 06 | | 236 14 | 31 |
| 20 | 200 42 | | 238 06 | 161 25 | | 255 43 | | 127 37 | | 238 39 | 30 |
| 30 | 203 12 | · · | 240 37 | 163 55 | · · | 258 14 | · · | 130 07 | · · | 241 04 | · 28 |
| 40 | 205 42 | | 243 07 | 166 25 | | 260 44 | | 132 37 | | 243 29 | 26 |
| 50 | 208 12 | | 245 38 | 168 55 | | 263 14 | | 135 08 | | 245 54 | 24 |
| 2 00 | 210 42 | N14 46 | 248 08 | 171 25 | N24 46 | 265 44 | S 9 08 | 137 38 | N22 31 | 248 19 | S 3 22 |
| 10 | 213 12 | | 250 38 | 173 54 | | 268 14 | | 140 09 | | 250 44 | 20 |
| 20 | 215 42 | | 253 09 | 176 24 | | 270 44 | | 142 39 | | 253 09 | 18 |
| 30 | 218 12 | · · | 255 39 | 178 54 | · · | 273 14 | · · | 145 09 | · · | 255 34 | · 16 |
| 40 | 220 42 | | 258 10 | 181 24 | | 275 44 | | 147 40 | | 257 59 | 14 |
| 50 | 223 12 | | 260 40 | 183 54 | | 278 14 | | 150 10 | | 260 24 | 12 |
| 3 00 | 225 42 | N14 47 | 263 10 | 186 24 | N24 46 | 280 45 | S 9 07 | 152 40 | N22 31 | 262 49 | S 3 11 |
| 10 | 228 12 | | 265 41 | 188 54 | | 283 15 | | 155 11 | | 265 14 | 09 |
| 20 | 230 43 | | 268 11 | 191 24 | | 285 45 | | 157 41 | | 267 39 | 07 |
| 30 | 233 13 | · · | 270 42 | 193 54 | · · | 288 15 | · · | 160 11 | · · | 270 04 | · 05 |
| 40 | 235 43 | | 273 12 | 196 23 | | 290 45 | | 162 42 | | 272 29 | 03 |
| 50 | 238 13 | | 275 42 | 198 53 | | 293 15 | | 165 12 | | 274 54 | 3 01 |
| 4 00 | 240 43 | N14 47 | 278 13 | 201 23 | N24 46 | 295 45 | S 9 07 | 167 42 | N22 31 | 277 20 | S 2 59 |
| 10 | 243 13 | | 280 43 | 203 53 | | 298 15 | | 170 13 | | 279 45 | 57 |
| 20 | 245 43 | | 283 14 | 206 23 | | 300 46 | | 172 43 | | 282 10 | 55 |
| 30 | 248 13 | · · | 285 44 | 208 53 | · · | 303 16 | · · | 175 13 | · · | 284 35 | · 53 |
| 40 | 250 43 | | 288 14 | 211 23 | | 305 46 | | 177 44 | | 287 00 | 51 |
| 50 | 253 13 | | 290 45 | 213 53 | | 308 16 | | 180 14 | | 289 25 | 50 |
| 5 00 | 255 43 | N14 48 | 293 15 | 216 22 | N24 47 | 310 46 | S 9 06 | 182 44 | N22 31 | 291 50 | S 2 48 |
| 10 | 258 13 | | 295 46 | 218 52 | | 313 16 | | 185 15 | | 294 15 | 46 |
| 20 | 260 43 | | 298 16 | 221 22 | | 315 46 | | 187 45 | | 296 40 | 44 |
| 30 | 263 13 | · · | 300 47 | 223 52 | · · | 318 16 | · · | 190 16 | · · | 299 05 | · 42 |
| 40 | 265 43 | | 303 17 | 226 22 | | 320 46 | | 192 46 | | 301 30 | 40 |
| 50 | 268 13 | | 305 47 | 228 52 | | 323 17 | | 195 16 | | 303 55 | 38 |
| 6 00 | 270 43 | N14 49 | 308 18 | 231 22 | N24 47 | 325 47 | S 9 05 | 197 47 | N22 31 | 306 20 | S 2 36 |
| 10 | 273 13 | | 310 48 | 233 52 | | 328 17 | | 200 17 | | 308 45 | 34 |
| 20 | 275 43 | | 313 19 | 236 21 | | 330 47 | | 202 47 | | 311 10 | 32 |
| 30 | 278 13 | · · | 315 49 | 238 51 | · · | 333 17 | · · | 205 18 | · · | 313 35 | · 30 |
| 40 | 280 43 | | 318 19 | 241 21 | | 335 47 | | 207 48 | | 316 00 | 29 |
| 50 | 283 13 | | 320 50 | 243 51 | | 338 17 | | 210 18 | | 318 25 | 27 |
| 7 00 | 285 43 | N14 50 | 323 20 | 246 21 | N24 47 | 340 47 | S 9 04 | 212 49 | N22 31 | 320 50 | S 2 25 |
| 10 | 288 13 | | 325 51 | 248 51 | | 343 17 | | 215 19 | | 323 15 | 23 |
| 20 | 290 43 | | 328 21 | 251 21 | | 345 48 | | 217 49 | | 325 40 | 21 |
| 30 | 293 13 | · · | 330 51 | 253 51 | · · | 348 18 | · · | 220 20 | · · | 328 05 | · 19 |
| 40 | 295 43 | | 333 22 | 256 21 | | 350 48 | | 222 50 | | 330 30 | 17 |
| 50 | 298 13 | | 335 52 | 258 50 | | 353 18 | | 225 20 | | 332 55 | 15 |
| 8 00 | 300 43 | N14 50 | 338 23 | 261 20 | N24 48 | 355 48 | S 9 04 | 227 51 | N22 31 | 335 20 | S 2 13 |
| 10 | 303 13 | | 340 53 | 263 50 | | 358 18 | | 230 21 | | 337 45 | 11 |
| 20 | 305 43 | | 343 24 | 266 20 | | 0 48 | | 232 51 | | 340 10 | 09 |
| 30 | 308 13 | · · | 345 54 | 268 50 | · · | 3 18 | · · | 235 22 | · · | 342 35 | · 07 |
| 40 | 310 43 | | 348 24 | 271 20 | | 5 49 | | 237 52 | | 345 00 | 06 |
| 50 | 313 13 | · | 350 55 | 273 50 | | 8 19 | | 240 23 | | 347 25 | 04 |
| 9 00 | 315 43 | N14 51 | 353 25 | 276 20 | N24 48 | 10 49 | S 9 03 | 242 53 | N22 31 | 349 50 | S 2 02 |
| 10 | 318 13 | | 355 56 | 278 49 | | 13 19 | | 245 23 | | 352 15 | 2 00 |
| 20 | 320 43 | | 358 26 | 281 19 | | 15 49 | | 247 54 | | 354 40 | 1 58 |
| 30 | 323 13 | · · | 0 56 | 283 49 | · · | 18 19 | · · | 250 24 | · · | 357 06 | · 56 |
| 40 | 325 43 | | 3 27 | 286 19 | | 20 49 | | 252 54 | | 359 31 | 54 |
| 50 | 328 13 | | 5 57 | 288 49 | | 23 19 | | 255 25 | | 1 56 | 52 |
| 10 00 | 330 43 | N14 52 | 8 28 | 291 19 | N24 48 | 25 49 | S 9 02 | 257 55 | N22 31 | 4 21 | S 1 50 |
| 10 | 333 13 | | 10 58 | 293 49 | | 28 20 | | 260 25 | | 6 46 | 48 |
| 20 | 335 43 | | 13 28 | 296 19 | | 30 50 | | 262 56 | | 9 11 | 46 |
| 30 | 338 13 | · · | 15 59 | 298 49 | · · | 33 20 | · · | 265 26 | · · | 11 36 | · 44 |
| 40 | 340 43 | | 18 29 | 301 18 | | 35 50 | | 267 56 | | 14 01 | 43 |
| 50 | 343 13 | | 21 00 | 303 48 | | 38 20 | | 270 27 | | 16 26 | 41 |
| 11 00 | 345 43 | N14 53 | 23 30 | 306 18 | N24 49 | 40 50 | S 9 02 | 272 57 | N22 31 | 18 51 | S 1 39 |
| 10 | 348 13 | | 26 01 | 308 48 | | 43 20 | | 275 27 | | 21 16 | 37 |
| 20 | 350 43 | | 28 31 | 311 18 | | 45 50 | | 277 58 | | 23 41 | 35 |
| 30 | 353 13 | · · | 31 01 | 313 48 | · · | 48 20 | · · | 280 28 | · · | 26 06 | · 33 |
| 40 | 355 43 | | 33 32 | 316 18 | | 50 51 | | 282 58 | | 28 31 | 31 |
| 50 | 358 13 | | 36 02 | 318 48 | | 53 21 | | 285 29 | | 30 56 | 29 |
| 12 00 | 0 43 | N14 53 | 38 33 | 321 17 | N24 49 | 55 51 | S 9 01 | 287 59 | N22 31 | 33 21 | S 1 27 |

☾ Par.

| Alt. | + Corr. |
|---|---|
| ° | ′ |
| 0 | |
| 8 | 58 |
| 13 | 57 |
| 17 | 56 |
| 20 | 55 |
| 22 | 54 |
| 25 | 53 |
| 27 | 52 |
| 29 | 51 |
| 31 | 50 |
| 33 | 49 |
| 35 | 48 |
| 36 | 47 |
| 38 | 46 |
| 40 | 45 |
| 41 | 44 |
| 42 | 43 |
| 44 | 42 |
| 45 | 41 |
| 47 | 40 |
| 48 | 39 |
| 49 | 38 |
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| 52 | 36 |
| 53 | 35 |
| 54 | 34 |
| 55 | 33 |
| 57 | 32 |
| 58 | 31 |
| 59 | 30 |
| 60 | 29 |
| 61 | 28 |
| 62 | 27 |
| 63 | 26 |
| 65 | 25 |
| 66 | 24 |
| 67 | 23 |
| 68 | 22 |
| 69 | 21 |
| 70 | 20 |
| 71 | 19 |
| 72 | 18 |
| 73 | 17 |
| 74 | 16 |
| 75 | 15 |
| 76 | 14 |
| 77 | 13 |
| 78 | 12 |
| 79 | 11 |
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SD ☉ ′ 16

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| Int. m | Corr. ′ |
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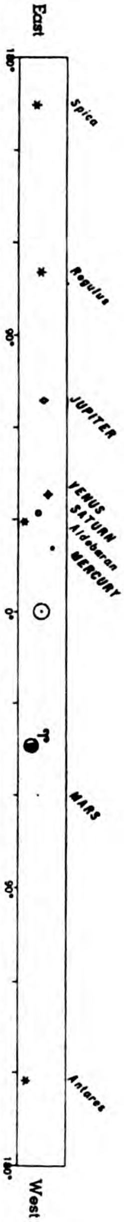

## GREENWICH P. M. 1943 MAY 1 (SATURDAY)

| GCT | ☉ SUN GHA | SUN Dec. | ♈ GHA | VENUS -3.5 GHA | VENUS Dec. | MARS 1.1 GHA | MARS Dec. | JUPITER -1.6 GHA | JUPITER Dec. | ◐ MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 00 | 0 43 | N14 53 | 38 33 | 321 17 | N24 49 | 55 51 | S 9 01 | 287 59 | N22 31 | 33 21 | S 1 27 |
| 10 | 3 13 | | 41 03 | 323 47 | | 58 21 | | 290 30 | | 35 46 | 25 |
| 20 | 5 43 | | 43 33 | 326 17 | | 60 51 | | 293 00 | | 38 11 | 23 |
| 30 | 8 13 | . . | 46 04 | 328 47 | . . | 63 21 | . . | 295 30 | . . | 40 36 | · 22 |
| 40 | 10 43 | | 48 34 | 331 17 | | 65 51 | | 298 01 | | 43 01 | 20 |
| 50 | 13 13 | | 51 05 | 333 47 | | 68 21 | | 300 31 | | 45 26 | 18 |
| 13 00 | 15 43 | N14 54 | 53 35 | 336 17 | N24 49 | 70 51 | S 9 00 | 303 01 | N22 31 | 47 52 | S 1 16 |
| 10 | 18 13 | | 56 05 | 338 47 | | 73 22 | | 305 32 | | 50 17 | 14 |
| 20 | 20 43 | | 58 36 | 341 16 | | 75 52 | | 308 02 | | 52 42 | 12 |
| 30 | 23 13 | . . | 61 06 | 343 46 | . . | 78 22 | . . | 310 32 | . . | 55 07 | · 10 |
| 40 | 25 43 | | 63 37 | 346 16 | | 80 52 | | 313 03 | | 57 32 | 08 |
| 50 | 28 13 | | 66 07 | 348 46 | | 83 22 | | 315 33 | | 59 57 | 06 |
| 14 00 | 30 43 | N14 55 | 68 37 | 351 16 | N24 50 | 85 52 | S 9 00 | 318 03 | N22 31 | 62 22 | S 1 04 |
| 10 | 33 13 | | 71 08 | 353 46 | | 88 22 | | 320 34 | | 64 47 | 02 |
| 20 | 35 43 | | 73 38 | 356 16 | | 90 52 | | 323 04 | | 67 12 | 1 00 |
| 30 | 38 13 | . . | 76 09 | 358 46 | . . | 93 23 | . . | 325 34 | . . | 69 37 | · 0 59 |
| 40 | 40 43 | | 78 39 | 1 16 | | 95 53 | | 328 05 | | 72 02 | 57 |
| 50 | 43 13 | | 81 10 | 3 45 | | 98 23 | | 330 35 | | 74 27 | 55 |
| 15 00 | 45 43 | N14 56 | 83 40 | 6 15 | N24 50 | 100 53 | S 8 59 | 333 05 | N22 31 | 76 52 | S 0 53 |
| 10 | 48 13 | | 86 10 | 8 45 | | 103 23 | | 335 36 | | 79 17 | 51 |
| 20 | 50 43 | | 88 41 | 11 15 | | 105 53 | | 338 06 | | 81 42 | 49 |
| 30 | 53 13 | . . | 91 11 | 13 45 | . . | 108 23 | . . | 340 37 | . . | 84 07 | · 47 |
| 40 | 55 43 | | 93 42 | 16 15 | | 110 53 | | 343 07 | | 86 32 | 45 |
| 50 | 58 13 | | 96 12 | 18 45 | | 113 23 | | 345 37 | | 88 58 | 43 |
| 16 00 | 60 43 | N14 57 | 98 42 | 21 15 | N24 51 | 115 54 | S 8 58 | 348 08 | N22 31 | 91 23 | S 0 41 |
| 10 | 63 14 | | 101 13 | 23 44 | | 118 24 | | 350 38 | | 93 48 | 39 |
| 20 | 65 44 | | 103 43 | 26 14 | | 120 54 | | 353 08 | | 96 13 | 37 |
| 30 | 68 14 | . . | 106 14 | 28 44 | . . | 123 24 | . . | 355 39 | . . | 98 38 | · 36 |
| 40 | 70 44 | | 108 44 | 31 14 | | 125 54 | | 358 09 | | 101 03 | 34 |
| 50 | 73 14 | | 111 14 | 33 44 | | 128 24 | | 0 39 | | 103 28 | 32 |
| 17 00 | 75 44 | N14 57 | 113 45 | 36 14 | N24 51 | 130 54 | S 8 58 | 3 10 | N22 31 | 105 53 | S 0 30 |
| 10 | 78 14 | | 116 15 | 38 44 | | 133 24 | | 5 40 | | 108 18 | 28 |
| 20 | 80 44 | | 118 46 | 41 14 | | 135 55 | | 8 10 | | 110 43 | 26 |
| 30 | 83 14 | . . | 121 16 | 43 44 | . . | 138 25 | . . | 10 41 | . . | 113 08 | · 24 |
| 40 | 85 44 | | 123 47 | 46 13 | | 140 55 | | 13 11 | | 115 33 | 22 |
| 50 | 88 14 | | 126 17 | 48 43 | | 143 25 | | 15 41 | | 117 58 | 20 |
| 18 00 | 90 44 | N14 58 | 128 47 | 51 13 | N24 51 | 145 55 | S 8 57 | 18 12 | N22 31 | 120 23 | S 0 18 |
| 10 | 93 14 | | 131 18 | 53 43 | | 148 25 | | 20 42 | | 122 48 | 16 |
| 20 | 95 44 | | 133 48 | 56 13 | | 150 55 | | 23 12 | | 125 14 | 14 |
| 30 | 98 14 | . . | 136 19 | 58 43 | . . | 153 25 | . . | 25 43 | . . | 127 39 | · 13 |
| 40 | 100 44 | | 138 49 | 61 13 | | 155 55 | | 28 13 | | 130 04 | 11 |
| 50 | 103 14 | | 141 19 | 63 43 | | 158 26 | | 30 44 | | 132 29 | 09 |
| 19 00 | 105 44 | N14 59 | 143 50 | 66 12 | N24 52 | 160 56 | S 8 56 | 33 14 | N22 31 | 134 54 | S 0 07 |
| 10 | 108 14 | | 146 20 | 68 42 | | 163 26 | | 35 44 | | 137 19 | 05 |
| 20 | 110 44 | | 148 51 | 71 12 | | 165 56 | | 38 15 | | 139 44 | 03 |
| 30 | 113 14 | . . | 151 21 | 73 42 | . . | 168 26 | . . | 40 45 | . . | 142 09 | S 0 01 |
| 40 | 115 44 | | 153 51 | 76 12 | | 170 56 | | 43 15 | | 144 34 | N 0 01 |
| 50 | 118 14 | | 156 22 | 78 42 | | 173 26 | | 45 46 | | 146 59 | 03 |
| 20 00 | 120 44 | N15 00 | 158 52 | 81 12 | N24 52 | 175 56 | S 8 55 | 48 16 | N22 30 | 149 24 | N 0 05 |
| 10 | 123 14 | | 161 23 | 83 42 | | 178 26 | | 50 46 | | 151 49 | 07 |
| 20 | 125 44 | | 163 53 | 86 11 | | 180 57 | | 53 17 | | 154 14 | 08 |
| 30 | 128 14 | . . | 166 24 | 88 41 | . . | 183 27 | . . | 55 47 | . . | 156 40 | · 10 |
| 40 | 130 44 | | 168 54 | 91 11 | | 185 57 | | 58 17 | | 159 05 | 12 |
| 50 | 133 14 | | 171 24 | 93 41 | | 188 27 | | 60 48 | | 161 30 | 14 |
| 21 00 | 135 44 | N15 00 | 173 55 | 96 11 | N24 52 | 190 57 | S 8 55 | 63 18 | N22 30 | 163 55 | N 0 16 |
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| 30 | 143 14 | . . | 181 26 | 103 41 | . . | 198 27 | . . | 70 49 | . . | 171 10 | · 22 |
| 40 | 145 44 | | 183 56 | 106 11 | | 200 58 | | 73 19 | | 173 35 | 24 |
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| 22 00 | 150 44 | N15 01 | 188 57 | 111 10 | N24 53 | 205 58 | S 8 54 | 78 20 | N22 30 | 178 25 | N 0 28 |
| 10 | 153 14 | | 191 28 | 113 40 | | 208 28 | | 80 51 | | 180 50 | 30 |
| 20 | 155 44 | | 193 58 | 116 10 | | 210 58 | | 83 21 | | 183 15 | 31 |
| 30 | 158 14 | . . | 196 28 | 118 40 | . . | 213 28 | . . | 85 51 | . . | 185 41 | · 33 |
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| 23 00 | 165 44 | N15 02 | 204 00 | 126 10 | N24 53 | 220 58 | S 8 53 | 93 22 | N22 30 | 192 56 | N 0 39 |
| 10 | 168 14 | | 206 30 | 128 39 | | 223 29 | | 95 53 | | 195 21 | 41 |
| 20 | 170 44 | | 209 00 | 131 09 | | 225 59 | | 98 23 | | 197 46 | 43 |
| 30 | 173 14 | . . | 211 31 | 133 39 | . . | 228 29 | . . | 100 53 | . . | 200 11 | 45 |
| 40 | 175 44 | | 214 01 | 136 09 | | 230 59 | | 103 24 | | 202 36 | 47 |
| 50 | 178 14 | | 216 32 | 138 39 | | 233 29 | | 105 54 | | 205 01 | 49 |
| 24 00 | 180 44 | N15 03 | 219 02 | 141 09 | N24 53 | 235 59 | S 8 53 | 108 24 | N22 30 | 207 26 | N 0 51 |

| Lat. | Sunrise | Twilt. | Moonrise | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | 2 36 | //// | 4 05 | * |
| 68 | 3 02 | 106 | 4 02 | 02 |
| 66 | 21 | 80 | 3 59 | 06 |
| 64 | 37 | 66 | 57 | 09 |
| 62 | 3 50 | 58 | 54 | 13 |
| 60 | 4 01 | 54 | 53 | 15 |
| 58 | 10 | 49 | 51 | 18 |
| 56 | 18 | 45 | 49 | 21 |
| 54 | 26 | 42 | 48 | 22 |
| 52 | 32 | 40 | 47 | 24 |
| 50 | 38 | 37 | 46 | 25 |
| 45 | 4 51 | 33 | 43 | 30 |
| 40 | 5 02 | 30 | 41 | 33 |
| 35 | 10 | 28 | 39 | 36 |
| 30 | 18 | 26 | 38 | 37 |
| 20 | 32 | 24 | 35 | 42 |
| 10 | 43 | 22 | 33 | 45 |
| 0 | 5 54 | 22 | 30 | 49 |
| 10 | 6 04 | 22 | 28 | 52 |
| 20 | 15 | 23 | 26 | 56 |
| 30 | 28 | 24 | 23 | 60 |
| 35 | 35 | 26 | 21 | 63 |
| 40 | 43 | 28 | 20 | 65 |
| 45 | 6 53 | 30 | 18 | 68 |
| 50 | 7 04 | 33 | 15 | 73 |
| 52 | 09 | 34 | 14 | 74 |
| 54 | 15 | 36 | 13 | 76 |
| 56 | 22 | 38 | 11 | 79 |
| 58 | 29 | 40 | 10 | 81 |
| 60 | 7 37 | 43 | 3 08 | 84 |
| S | | | | |

| Lat. | Sunset | Twilt. | Moonset | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | 21 22 | //// | 15 44 | 105 |
| 68 | 20 56 | 109 | 45 | 99 |
| 66 | 36 | 82 | 46 | 94 |
| 64 | 20 | 68 | 47 | 89 |
| 62 | 20 07 | 59 | 47 | 87 |
| 60 | 19 55 | 54 | 48 | 83 |
| 58 | 45 | 48 | 48 | 81 |
| 56 | 37 | 44 | 49 | 78 |
| 54 | 30 | 41 | 49 | 76 |
| 52 | 23 | 39 | 50 | 74 |
| 50 | 17 | 36 | 50 | 72 |
| 45 | 19 04 | 32 | 50 | 69 |
| 40 | 18 53 | 29 | 51 | 65 |
| 35 | 44 | 27 | 52 | 62 |
| 30 | 37 | 25 | 52 | 60 |
| 20 | 23 | 23 | 53 | 56 |
| 10 | 12 | 22 | 53 | 52 |
| 0 | 18 01 | 22 | 54 | 48 |
| 10 | 17 49 | 22 | 54 | 46 |
| 20 | 38 | 23 | 55 | 41 |
| 30 | 25 | 24 | 55 | 38 |
| 35 | 18 | 26 | 56 | 35 |
| 40 | 10 | 28 | 56 | 33 |
| 45 | 17 00 | 31 | 56 | 30 |
| 50 | 16 48 | 33 | 57 | 26 |
| 52 | 43 | 35 | 57 | 24 |
| 54 | 37 | 37 | 57 | 23 |
| 56 | 31 | 40 | 58 | 20 |
| 58 | 23 | 42 | 58 | 18 |
| 60 | 16 15 | 44 | 15 58 | 16 |
| S | | | | |



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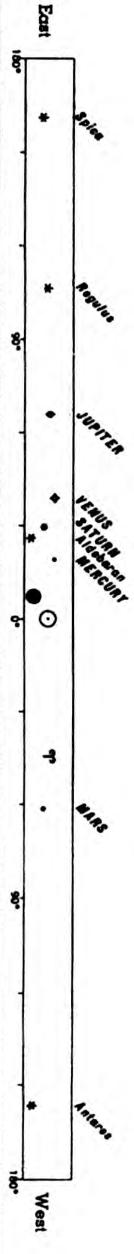
# GREENWICH A. M. 1943 MAY 5 (WEDNESDAY)

| GCT | ☉ SUN GHA | ☉ SUN Dec. | ♈ GHA | VENUS - 3.5 GHA | VENUS - 3.5 Dec. | MARS 1.1 GHA | MARS 1.1 Dec. | JUPITER - 1.6 GHA | JUPITER - 1.6 Dec. | ● MOON GHA | ● MOON Dec. | ☾ Par. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | |
| 0 00 | 180 49 | N15 56 | 222 00 | 140 17 | N25 15 | 236 49 | S 8 02 | 110 54 | N22 27 | 172 17 | N13 07 | |
| 10 | 183 19 | | 224 30 | 142 46 | | 239 19 | | 113 25 | | 174 42 | 08 | |
| 20 | 185 49 | | 227 00 | 145 16 | | 241 50 | | 115 55 | | 177 07 | 10 | |
| 30 | 188 19 | · · | 229 31 | 147 46 | · · | 244 20 | · · | 118 25 | · · | 179 33 | · 11 | |
| 40 | 190 49 | | 232 01 | 150 16 | | 246 50 | | 120 56 | | 181 58 | 13 | |
| 50 | 193 19 | | 234 32 | 152 46 | | 249 20 | | 123 26 | | 184 23 | 14 | |
| 1 00 | 195 49 | N15 57 | 237 02 | 155 16 | N25 15 | 251 50 | S 8 02 | 125 56 | N22 27 | 186 48 | N13 15 | Alt. Corr. |
| 10 | 198 19 | | 239 32 | 157 46 | | 254 20 | | 128 27 | | 189 13 | 17 | |
| 20 | 200 49 | | 242 03 | 160 16 | | 256 50 | | 130 57 | | 191 38 | 18 | ° + ′ |
| 30 | 203 19 | · · | 244 33 | 162 45 | · · | 259 20 | · · | 133 27 | · · | 194 03 | · 19 | 0 |
| 40 | 205 49 | | 247 04 | 165 15 | | 261 50 | | 135 58 | | 196 28 | 21 | 7 56 |
| 50 | 208 19 | | 249 34 | 167 45 | | 264 21 | | 138 28 | | 198 53 | 22 | 13 55 |
| 2 00 | 210 49 | N15 57 | 252 04 | 170 15 | N25 15 | 266 51 | S 8 01 | 140 58 | N22 27 | 201 18 | N13 24 | 17 54 |
| 10 | 213 19 | | 254 35 | 172 45 | | 269 21 | | 143 29 | | 203 43 | 25 | 20 53 |
| 20 | 215 49 | | 257 05 | 175 15 | | 271 51 | | 145 59 | | 206 09 | 26 | 23 52 |
| 30 | 218 19 | · · | 259 36 | 177 45 | · · | 274 21 | · · | 148 29 | · · | 208 34 | · 28 | 25 51 |
| 40 | 220 49 | | 262 06 | 180 15 | | 276 51 | | 151 00 | | 210 59 | 29 | 27 50 |
| 50 | 223 19 | | 264 37 | 182 44 | | 279 21 | | 153 30 | | 213 24 | 30 | 29 49 |
| | | | | | | | | | | | | 31 48 |
| 3 00 | 225 49 | N15 58 | 267 07 | 185 14 | N25 15 | 281 51 | S 8 00 | 156 01 | N22 27 | 215 49 | N13 32 | 33 47 |
| 10 | 228 19 | | 269 37 | 187 44 | | 284 22 | | 158 31 | | 218 14 | 33 | 35 46 |
| 20 | 230 49 | | 272 08 | 190 14 | | 286 52 | | 161 01 | | 220 39 | 34 | 37 45 |
| 30 | 233 19 | · · | 274 38 | 192 44 | · · | 289 22 | · · | 163 32 | · · | 223 04 | · 36 | 39 44 |
| 40 | 235 49 | | 277 09 | 195 14 | | 291 52 | | 166 02 | | 225 29 | 37 | 40 43 |
| 50 | 238 19 | | 279 39 | 197 44 | | 294 22 | | 168 32 | | 227 54 | 38 | 42 42 |
| 4 00 | 240 49 | N15 59 | 282 09 | 200 14 | N25 16 | 296 52 | S 8 00 | 171 03 | N22 27 | 230 19 | N13 40 | 43 41 |
| 10 | 243 19 | | 284 40 | 202 43 | | 299 22 | | 173 33 | | 232 45 | 41 | 45 40 |
| 20 | 245 49 | | 287 10 | 205 13 | | 301 52 | | 176 03 | | 235 10 | 42 | 46 39 |
| 30 | 248 19 | · · | 289 41 | 207 43 | · · | 304 22 | · · | 178 34 | · · | 237 35 | · 44 | 47 38 |
| 40 | 250 49 | | 292 11 | 210 13 | | 306 53 | | 181 04 | | 240 00 | 45 | 49 37 |
| 50 | 253 19 | | 294 41 | 212 43 | | 309 23 | | 183 34 | | 242 25 | 46 | 50 36 |
| 5 00 | 255 49 | N16 00 | 297 12 | 215 13 | N25 16 | 311 53 | S 7 59 | 186 05 | N22 27 | 244 50 | N13 48 | 51 35 |
| 10 | 258 19 | | 299 42 | 217 43 | | 314 23 | | 188 35 | | 247 15 | 49 | 53 34 |
| 20 | 260 49 | | 302 13 | 220 13 | | 316 53 | | 191 05 | | 249 40 | 50 | 54 33 |
| 30 | 263 19 | · · | 304 43 | 222 43 | · · | 319 23 | · · | 193 36 | · · | 252 05 | · 52 | 55 32 |
| 40 | 265 49 | | 307 14 | 225 12 | | 321 53 | | 196 06 | | 254 30 | 53 | 56 31 |
| 50 | 268 19 | | 309 44 | 227 42 | | 324 23 | | 198 36 | | 256 55 | 54 | 58 30 |
| | | | | | | | | | | | | 59 29 |
| 6 00 | 270 49 | N16 00 | 312 14 | 230 12 | N25 16 | 326 54 | S 7 58 | 201 07 | N22 26 | 259 21 | N13 56 | 60 28 |
| 10 | 273 19 | | 314 45 | 232 42 | | 329 24 | | 203 37 | | 261 46 | 57 | 61 27 |
| 20 | 275 49 | | 317 15 | 235 12 | | 331 54 | | 206 07 | | 264 11 | 58 | 62 26 |
| 30 | 278 19 | · · | 319 46 | 237 42 | · · | 334 24 | · · | 208 38 | · · | 266 36 | ·13 59 | 64 25 |
| 40 | 280 49 | | 322 16 | 240 12 | | 336 54 | | 211 08 | | 269 01 | 14 01 | 65 24 |
| 50 | 283 19 | | 324 46 | 242 42 | | 339 24 | | 213 38 | | 271 26 | 02 | 66 23 |
| 7 00 | 285 49 | N16 01 | 327 17 | 245 11 | N25 16 | 341 54 | S 7 57 | 216 09 | N22 26 | 273 51 | N14 03 | 67 22 |
| 10 | 288 19 | | 329 47 | 247 41 | | 344 24 | | 218 39 | | 276 16 | 05 | 68 21 |
| 20 | 290 49 | | 332 18 | 250 11 | | 346 54 | | 221 00 | | 278 41 | 06 | 69 20 |
| 30 | 293 19 | · · | 334 48 | 252 41 | · · | 349 25 | · · | 223 40 | · · | 281 06 | · 07 | 70 19 |
| 40 | 295 49 | | 337 18 | 255 11 | | 351 55 | | 226 10 | | 283 31 | 09 | 71 18 |
| 50 | 298 19 | | 339 49 | 257 41 | | 354 25 | | 228 41 | | 285 56 | 10 | 72 17 |
| 8 00 | 300 50 | N16 02 | 342 19 | 260 11 | N25 17 | 356 55 | S 7 57 | 231 11 | N22 26 | 288 22 | N14 11 | 73 16 |
| 10 | 303 20 | | 344 50 | 262 41 | | 359 25 | | 233 41 | | 290 47 | 12 | 74 15 |
| 20 | 305 50 | | 347 20 | 265 10 | | 1 55 | | 236 12 | | 293 12 | 14 | 76 14 |
| 30 | 308 20 | · · | 349 50 | 267 40 | · · | 4 25 | · · | 238 42 | · · | 295 37 | · 15 | 77 13 |
| 40 | 310 50 | | 352 21 | 270 10 | | 6 55 | | 241 12 | | 298 02 | 16 | 78 12 |
| 50 | 313 20 | | 354 51 | 272 40 | | 9 26 | | 243 43 | | 300 27 | 17 | 79 11 |
| | | | | | | | | | | | | 80 10 |
| 9 00 | 315 50 | N16 02 | 357 22 | 275 10 | N25 17 | 11 56 | S 7 56 | 246 13 | N22 26 | 302 52 | N14 19 | |
| 10 | 318 20 | | 359 52 | 277 40 | | 14 26 | | 248 43 | | 305 17 | 20 | |
| 20 | 320 50 | | 2 23 | 280 10 | | 16 56 | | 251 14 | | 307 42 | 21 | SD, ☉ ′ |
| 30 | 323 20 | · · | 4 53 | 282 40 | · · | 19 26 | · · | 253 44 | · · | 310 07 | · 23 | |
| 40 | 325 50 | | 7 23 | 285 09 | | 21 56 | | 256 14 | | 312 32 | 24 | 16 |
| 50 | 328 20 | | 9 54 | 287 39 | | 24 26 | | 258 45 | | 314 57 | 25 | |
| 10 00 | 330 50 | N16 03 | 12 24 | 290 09 | N25 17 | 26 56 | S 7 55 | 261 15 | N22 26 | 317 22 | N14 26 | SD, ☾ ′ |
| 10 | 333 20 | | 14 55 | 292 39 | | 29 26 | | 263 45 | | 319 47 | 28 | |
| 20 | 335 50 | | 17 25 | 295 09 | | 31 57 | | 266 16 | | 322 13 | 29 | 15 |
| 30 | 338 20 | · · | 19 55 | 297 39 | · · | 34 27 | · · | 268 46 | · · | 324 38 | · 30 | |
| 40 | 340 50 | | 22 26 | 300 09 | | 36 57 | | 271 16 | | 327 03 | 31 | Corr. |
| 50 | 343 20 | | 24 56 | 302 39 | | 39 27 | | 273 47 | | 329 28 | 33 | HA ☾ |
| 11 00 | 345 50 | N16 04 | 27 27 | 305 08 | N25 17 | 41 57 | S 7 55 | 276 17 | N22 26 | 331 53 | N14 34 | |
| 10 | 348 20 | | 29 57 | 307 38 | | 44 27 | | 278 47 | | 334 18 | 35 | Int. Corr. |
| 20 | 350 50 | | 32 27 | 310 08 | | 46 57 | | 281 18 | | 336 43 | 36 | |
| 30 | 353 20 | · · | 34 58 | 312 38 | · · | 49 27 | · · | 283 48 | · · | 339 08 | · 38 | m ′ |
| 40 | 355 50 | | 37 28 | 315 08 | | 51 58 | | 286 18 | | 341 33 | 39 | 0 |
| 50 | 358 20 | | 39 59 | 317 38 | | 54 28 | | 288 49 | | 343 58 | 40 | 10 0 |
| 12 00 | 0 50 | N16 05 | 42 29 | 320 08 | N25 18 | 56 58 | S 7 54 | 291 19 | N22 26 | 346 23 | N14 41 | |



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# GREENWICH P. M. 1943 MAY 5 (WEDNESDAY)

| GCT h | GCT m | ☉ SUN GHA | SUN Dec. | ♈ GHA | VENUS −3.5 GHA | VENUS Dec. | MARS 1.1 GHA | MARS Dec. | JUPITER −1.6 GHA | JUPITER Dec. | ● MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| h | m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 | 00 | 0 50 | N16 05 | 42 29 | 320 08 | N25 18 | 56 58 | S 7 54 | 291 19 | N22 26 | 346 23 | N14 41 |
| | 10 | 3 20 | | 45 00 | 322 38 | | 59 28 | | 293 49 | | 348 48 | 42 |
| | 20 | 5 50 | | 47 30 | 325 08 | | 61 58 | | 296 20 | | 351 14 | 44 |
| | 30 | 8 20 | · · | 50 00 | 327 37 | · · | 64 28 | · · | 298 50 | · · | 353 39 | · 45 |
| | 40 | 10 50 | | 52 31 | 330 07 | | 66 58 | | 301 20 | | 356 04 | 46 |
| | 50 | 13 20 | | 55 01 | 332 37 | | 69 28 | | 303 51 | | 358 29 | 47 |
| 13 | 00 | 15 50 | N16 05 | 57 32 | 335 07 | N25 18 | 71 58 | S 7 53 | 306 21 | N22 26 | 0 54 | N14 49 |
| | 10 | 18 20 | | 60 02 | 337 37 | | 74 29 | | 308 52 | | 3 19 | 50 |
| | 20 | 20 50 | | 62 32 | 340 07 | | 76 59 | | 311 22 | | 5 44 | 51 |
| | 30 | 23 20 | · · | 65 03 | 342 37 | · · | 79 29 | · · | 313 52 | · · | 8 09 | · 52 |
| | 40 | 25 50 | | 67 33 | 345 07 | | 81 59 | | 316 23 | | 10 34 | 53 |
| | 50 | 28 20 | | 70 04 | 347 36 | | 84 29 | | 318 53 | | 12 59 | 55 |
| 14 | 00 | 30 50 | N16 06 | 72 34 | 350 06 | N25 18 | 86 59 | S 7 53 | 321 23 | N22 26 | 15 24 | N14 56 |
| | 10 | 33 20 | | 75 04 | 352 36 | | 89 29 | | 323 54 | | 17 49 | 57 |
| | 20 | 35 50 | | 77 35 | 355 06 | | 91 59 | | 326 24 | | 20 14 | 58 |
| | 30 | 38 20 | · · | 80 05 | 357 36 | · · | 94 29 | · · | 328 54 | · · | 22 40 | · 14 59 |
| | 40 | 40 50 | | 82 36 | 0 06 | | 97 00 | | 331 25 | | 25 05 | 15 01 |
| | 50 | 43 20 | | 85 06 | 2 36 | | 99 30 | | 333 55 | | 27 30 | 02 |
| 15 | 00 | 45 50 | N16 07 | 87 37 | 5 06 | N25 18 | 102 00 | S 7 52 | 336 25 | N22 26 | 29 55 | N15 03 |
| | 10 | 48 20 | | 90 07 | 7 35 | | 104 30 | | 338 56 | | 32 20 | 04 |
| | 20 | 50 50 | | 92 37 | 10 05 | | 107 00 | | 341 26 | | 34 45 | 05 |
| | 30 | 53 20 | · · | 95 08 | 12 35 | · · | 109 30 | · · | 343 56 | · · | 37 10 | · 07 |
| | 40 | 55 50 | | 97 38 | 15 05 | | 112 00 | | 346 27 | | 39 35 | 08 |
| | 50 | 58 20 | | 100 09 | 17 35 | | 114 30 | | 348 57 | | 42 00 | 09 |
| 16 | 00 | 60 50 | N16 08 | 102 39 | 20 05 | N25 19 | 117 01 | S 7 51 | 351 27 | N22 26 | 44 25 | N15 10 |
| | 10 | 63 20 | | 105 09 | 22 35 | | 119 31 | | 353 58 | | 46 50 | 11 |
| | 20 | 65 50 | | 107 40 | 25 05 | | 122 01 | | 356 28 | | 49 15 | 12 |
| | 30 | 68 20 | · · | 110 10 | 27 34 | · · | 124 31 | · · | 358 58 | · · | 51 40 | · 14 |
| | 40 | 70 50 | | 112 41 | 30 04 | | 127 01 | | 1 29 | | 54 05 | 15 |
| | 50 | 73 20 | | 115 11 | 32 34 | | 129 31 | | 3 59 | | 56 31 | 16 |
| 17 | 00 | 75 50 | N16 08 | 117 41 | 35 04 | N25 19 | 132 01 | S 7 50 | 6 29 | N22 26 | 58 56 | N15 17 |
| | 10 | 78 20 | | 120 12 | 37 34 | | 134 31 | | 9 00 | | 61 21 | 18 |
| | 20 | 80 50 | | 122 42 | 40 04 | | 137 01 | | 11 30 | | 63 46 | 19 |
| | 30 | 83 20 | · · | 125 13 | 42 34 | · · | 139 32 | · · | 14 00 | · · | 66 11 | · 21 |
| | 40 | 85 50 | | 127 43 | 45 04 | | 142 02 | | 16 31 | | 68 36 | 22 |
| | 50 | 88 20 | | 130 13 | 47 33 | | 144 32 | | 19 01 | | 71 01 | 23 |
| 18 | 00 | 90 50 | N16 09 | 132 44 | 50 03 | N25 19 | 147 02 | S 7 50 | 21 32 | N22 26 | 73 26 | N15 24 |
| | 10 | 93 20 | | 135 14 | 52 33 | | 149 32 | | 24 02 | | 75 51 | 25 |
| | 20 | 95 50 | | 137 45 | 55 03 | | 152 02 | | 26 32 | | 78 16 | 26 |
| | 30 | 98 20 | · · | 140 15 | 57 33 | · · | 154 32 | · · | 29 03 | · · | 80 41 | · 27 |
| | 40 | 100 50 | | 142 46 | 60 03 | | 157 02 | | 31 33 | | 83 06 | 29 |
| | 50 | 103 20 | | 145 16 | 62 33 | | 159 33 | | 34 03 | | 85 31 | 30 |
| 19 | 00 | 105 50 | N16 10 | 147 46 | 65 03 | N25 19 | 162 03 | S 7 49 | 36 34 | N22 26 | 87 56 | N15 31 |
| | 10 | 108 20 | | 150 17 | 67 32 | | 164 33 | | 39 04 | | 90 21 | 32 |
| | 20 | 110 50 | | 152 47 | 70 02 | | 167 03 | | 41 34 | | 92 47 | 33 |
| | 30 | 113 20 | · · | 155 18 | 72 32 | · · | 169 33 | · · | 44 05 | · · | 95 12 | · 34 |
| | 40 | 115 50 | | 157 48 | 75 02 | | 172 03 | | 46 35 | | 97 37 | 35 |
| | 50 | 118 20 | | 160 18 | 77 32 | | 174 33 | | 49 05 | | 100 02 | 37 |
| 20 | 00 | 120 50 | N16 10 | 162 49 | 80 02 | N25 20 | 177 03 | S 7 48 | 51 36 | N22 26 | 102 27 | N15 38 |
| | 10 | 123 20 | | 165 19 | 82 32 | | 179 33 | | 54 06 | | 104 52 | 39 |
| | 20 | 125 50 | | 167 50 | 85 02 | | 182 04 | | 56 36 | | 107 17 | 40 |
| | 30 | 128 20 | · · | 170 20 | 87 32 | · · | 184 34 | · · | 59 07 | · · | 109 42 | · 41 |
| | 40 | 130 50 | | 172 50 | 90 01 | | 187 04 | | 61 37 | | 112 07 | 42 |
| | 50 | 133 20 | | 175 21 | 92 31 | | 189 34 | | 64 07 | | 114 32 | 43 |
| 21 | 00 | 135 50 | N16 11 | 177 51 | 95 01 | N25 20 | 192 04 | S 7 48 | 66 38 | N22 26 | 116 57 | N15 44 |
| | 10 | 138 20 | | 180 22 | 97 31 | | 194 34 | | 69 08 | | 119 22 | 46 |
| | 20 | 140 50 | | 182 52 | 100 01 | | 197 04 | | 71 38 | | 121 47 | 47 |
| | 30 | 143 20 | · · | 185 23 | 102 31 | · · | 199 34 | · · | 74 09 | · · | 124 12 | · 48 |
| | 40 | 145 50 | | 187 53 | 105 01 | | 202 05 | | 76 39 | | 126 37 | 49 |
| | 50 | 148 20 | | 190 23 | 107 31 | | 204 35 | | 79 09 | | 129 02 | 50 |
| 22 | 00 | 150 50 | N16 12 | 192 54 | 110 00 | N25 20 | 207 05 | S 7 47 | 81 40 | N22 26 | 131 28 | N15 51 |
| | 10 | 153 20 | | 195 24 | 112 30 | | 209 35 | | 84 10 | | 133 53 | 52 |
| | 20 | 155 50 | | 197 55 | 115 00 | | 212 05 | | 86 40 | | 136 18 | 53 |
| | 30 | 158 20 | · · | 200 25 | 117 30 | · · | 214 35 | · · | 89 11 | · · | 138 43 | · 54 |
| | 40 | 160 50 | | 202 55 | 120 00 | | 217 05 | | 91 41 | | 141 08 | 55 |
| | 50 | 163 20 | | 205 26 | 122 30 | | 219 35 | | 94 12 | | 143 33 | 56 |
| 23 | 00 | 165 50 | N16 13 | 207 56 | 125 00 | N25 20 | 222 05 | S 7 46 | 96 42 | N22 26 | 145 58 | N15 58 |
| | 10 | 168 20 | | 210 27 | 127 30 | | 224 36 | | 99 12 | | 148 23 | 15 59 |
| | 20 | 170 50 | | 212 57 | 129 59 | | 227 06 | | 101 43 | | 150 48 | 16 00 |
| | 30 | 173 20 | · · | 215 27 | 132 29 | · · | 229 36 | · · | 104 13 | · · | 153 13 | · 01 |
| | 40 | 175 50 | | 217 58 | 134 59 | | 232 06 | | 106 43 | | 155 38 | 02 |
| | 50 | 178 20 | | 220 28 | 137 29 | | 234 36 | | 109 14 | | 158 03 | 03 |
| 24 | 00 | 180 50 | N16 13 | 222 59 | 139 59 | N25 21 | 237 06 | S 7 46 | 111 44 | N22 26 | 160 28 | N16 04 |

| Lat. | Sunrise h | Sunrise m | Twil. | Moonrise h | Moonrise m | Diff. |
|---|---|---|---|---|---|---|
| N ° | h | m | m | h | m | m |
| 70 | 2 | 12 | //// | 3 | 53 | * |
| 68 | 2 | 43 | 148 | 4 | 12 | 07 |
| 66 | 3 | 05 | 89 | | 28 | 13 |
| 64 | | 23 | 72 | | 40 | 19 |
| 62 | | 38 | 62 | 4 | 52 | 21 |
| 60 | 3 | 50 | 57 | 5 | 01 | 24 |
| 58 | 4 | 00 | 51 | | 09 | 27 |
| 56 | | 10 | 47 | | 17 | 28 |
| 54 | | 18 | 44 | | 23 | 30 |
| 52 | | 25 | 41 | | 29 | 31 |
| 50 | | 31 | 38 | | 34 | 33 |
| 45 | | 45 | 34 | | 46 | 35 |
| 40 | 4 | 57 | 31 | 5 | 55 | 38 |
| 35 | 5 | 06 | 28 | 6 | 03 | 40 |
| 30 | | 15 | 26 | | 10 | 42 |
| 20 | | 29 | 24 | | 23 | 44 |
| 10 | | 42 | 22 | | 34 | 47 |
| 0 | 5 | 53 | 22 | | 45 | 48 |
| 10 | 6 | 05 | 22 | 6 | 55 | 51 |
| 20 | | 17 | 23 | 7 | 06 | 54 |
| 30 | | 31 | 24 | | 19 | 56 |
| 35 | | 39 | 26 | | 27 | 57 |
| 40 | | 48 | 28 | | 35 | 60 |
| 45 | 6 | 58 | 31 | | 45 | 62 |
| 50 | 7 | 11 | 33 | 7 | 57 | 65 |
| 52 | | 17 | 35 | 8 | 03 | 66 |
| 54 | | 23 | 37 | | 09 | 68 |
| 56 | | 30 | 39 | | 16 | 70 |
| 58 | | 39 | 42 | | 24 | 71 |
| 60 | 7 | 48 | 45 | 8 | 33 | 74 |
| S | | | | | | |

| Lat. | Sunset h | Sunset m | Twil. | Moonset h | Moonset m | Diff. |
|---|---|---|---|---|---|---|
| N ° | h | m | m | h | m | m |
| 70 | 21 | 46 | //// | 22 | 40 | 103 |
| 68 | 21 | 14 | //// | 22 | 12 | 89 |
| 66 | 20 | 51 | 92 | 21 | 51 | 81 |
| 64 | | 33 | 74 | | 34 | 77 |
| 62 | | 18 | 63 | | 20 | 74 |
| 60 | 20 | 05 | 57 | 21 | 08 | 71 |
| 58 | 19 | 54 | 50 | 20 | 58 | 69 |
| 56 | | 45 | 46 | | 50 | 66 |
| 54 | | 37 | 43 | | 42 | 65 |
| 52 | | 30 | 40 | | 35 | 64 |
| 50 | | 23 | 37 | | 28 | 63 |
| 45 | 19 | 09 | 34 | | 15 | 60 |
| 40 | 18 | 57 | 30 | 20 | 04 | 58 |
| 35 | | 48 | 27 | 19 | 55 | 56 |
| 30 | | 39 | 25 | | 46 | 56 |
| 20 | | 25 | 23 | | 32 | 53 |
| 10 | | 12 | 22 | | 20 | 51 |
| 0 | 18 | 00 | 22 | 19 | 08 | 49 |
| 10 | 17 | 49 | 22 | 18 | 56 | 48 |
| 20 | | 36 | 23 | | 44 | 45 |
| 30 | | 22 | 25 | | 30 | 43 |
| 35 | | 14 | 27 | | 22 | 41 |
| 40 | 17 | 05 | 29 | | 12 | 40 |
| 45 | 16 | 55 | 32 | 18 | 02 | 37 |
| 50 | | 42 | 34 | 17 | 49 | 35 |
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| 58 | | 14 | 43 | | 20 | 29 |
| 60 | 16 | 05 | 46 | 17 | 10 | 28 |
| S | | | | | | |



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## GREENWICH A. M. 1943 MAY 10 (MONDAY)

| GCT | ☉ SUN GHA | ☉ SUN Dec. | ♈ GHA | VENUS −3.6 GHA | VENUS Dec. | MARS 0.9 GHA | MARS Dec. | JUPITER −1.5 GHA | JUPITER Dec. | ◐ MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
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| 20 | 185 55 | | 231 56 | 143 49 | | 243 14 | | 120 02 | | 118 05 | 14 |
| 30 | 188 25 | · · | 234 26 | 146 19 | · · | 245 45 | · · | 122 33 | · · | 120 31 | · 14 |
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| 30 | 203 25 | · · | 249 29 | 161 18 | · · | 260 45 | · · | 137 35 | · · | 135 02 | · 11 |
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| 50 | 208 25 | | 254 30 | 166 18 | | 265 46 | | 142 36 | | 139 52 | 10 |
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| 10 | 213 25 | | 259 31 | 171 18 | | 270 46 | | 147 36 | | 144 42 | 09 |
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| 40 | 220 55 | | 267 02 | 178 48 | | 278 16 | | 155 07 | | 151 58 | 08 |
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| 3 00 | 225 55 | N17 22 | 272 03 | 183 47 | N25 37 | 283 16 | S 6 35 | 160 08 | N22 20 | 156 48 | N19 07 |
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| 30 | 233 25 | · · | 279 34 | 191 17 | · · | 290 47 | · · | 167 39 | · · | 164 04 | · 06 |
| 40 | 235 55 | | 282 04 | 193 47 | | 293 17 | | 170 09 | | 166 29 | 05 |
| 50 | 238 25 | | 284 35 | 196 17 | | 295 47 | | 172 40 | | 168 54 | 05 |
| 4 00 | 240 55 | N17 22 | 287 05 | 198 47 | N25 37 | 298 17 | S 6 35 | 175 10 | N22 20 | 171 20 | N19 04 |
| 10 | 243 25 | | 289 36 | 201 17 | | 300 47 | | 177 40 | | 173 45 | 04 |
| 20 | 245 55 | | 292 06 | 203 46 | | 303 17 | | 180 11 | | 176 10 | 03 |
| 30 | 248 25 | · · | 294 36 | 206 16 | · · | 305 48 | · · | 182 41 | · · | 178 35 | · 03 |
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| 50 | 253 25 | | 299 37 | 211 16 | | 310 48 | | 187 42 | | 183 26 | 02 |
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| 30 | 263 25 | · · | 309 39 | 221 16 | · · | 320 48 | · · | 197 43 | · · | 193 07 | · 00 |
| 40 | 265 55 | | 312 09 | 223 45 | | 323 18 | | 200 13 | | 195 32 | 19 00 |
| 50 | 268 25 | | 314 40 | 226 15 | | 325 48 | | 202 44 | | 197 57 | 18 59 |
| 6 00 | 270 55 | N17 24 | 317 10 | 228 45 | N25 37 | 328 19 | S 6 33 | 205 14 | N22 20 | 200 22 | N18 59 |
| 10 | 273 25 | | 319 40 | 231 15 | | 330 49 | | 207 44 | | 202 47 | 58 |
| 20 | 275 55 | | 322 11 | 233 45 | | 333 19 | | 210 15 | | 205 13 | 58 |
| 30 | 278 25 | · · | 324 41 | 236 15 | · · | 335 49 | · · | 212 45 | · · | 207 38 | · 57 |
| 40 | 280 55 | | 327 12 | 238 45 | | 338 19 | | 215 15 | | 210 03 | 57 |
| 50 | 283 25 | | 329 42 | 241 15 | | 340 49 | | 217 46 | | 212 28 | 56 |
| 7 00 | 285 55 | N17 24 | 332 12 | 243 45 | N25 37 | 343 19 | S 6 33 | 220 16 | N22 20 | 214 54 | N18 56 |
| 10 | 288 25 | | 334 43 | 246 14 | | 345 49 | | 222 46 | | 217 19 | 55 |
| 20 | 290 55 | | 337 13 | 248 44 | | 348 20 | | 225 17 | | 219 44 | 55 |
| 30 | 293 25 | · · | 339 44 | 251 14 | · · | 350 50 | · · | 227 47 | · · | 222 09 | · 54 |
| 40 | 295 55 | | 342 14 | 253 44 | | 353 20 | | 230 17 | | 224 34 | 54 |
| 50 | 298 25 | | 344 45 | 256 14 | | 355 50 | | 232 48 | | 227 00 | 53 |
| 8 00 | 300 55 | N17 25 | 347 15 | 258 44 | N25 38 | 358 20 | S 6 32 | 235 18 | N22 20 | 229 25 | N18 53 |
| 10 | 303 25 | | 349 45 | 261 14 | | 0 50 | | 237 48 | | 231 50 | 52 |
| 20 | 305 55 | | 352 16 | 263 44 | | 3 20 | | 240 19 | | 234 15 | 51 |
| 30 | 308 25 | · · | 354 46 | 266 13 | · · | 5 50 | · · | 242 49 | · · | 236 41 | · 51 |
| 40 | 310 55 | | 357 17 | 268 43 | | 8 21 | | 245 19 | | 239 06 | 50 |
| 50 | 313 25 | | 359 47 | 271 13 | | 10 51 | | 247 50 | | 241 31 | 50 |
| 9 00 | 315 55 | N17 26 | 2 17 | 273 43 | N25 38 | 13 21 | S 6 31 | 250 20 | N22 20 | 243 56 | N18 49 |
| 10 | 318 25 | | 4 48 | 276 13 | | 15 51 | | 252 51 | | 246 21 | 49 |
| 20 | 320 55 | | 7 18 | 278 43 | | 18 21 | | 255 21 | | 248 47 | 48 |
| 30 | 323 25 | · · | 9 49 | 281 13 | · · | 20 51 | · · | 257 51 | · · | 251 12 | · 48 |
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| 50 | 328 25 | | 14 49 | 286 12 | | 25 51 | | 262 52 | | 256 02 | 47 |
| 10 00 | 330 55 | N17 26 | 17 20 | 288 42 | N25 38 | 28 21 | S 6 30 | 265 22 | N22 20 | 258 28 | N18 46 |
| 10 | 333 25 | | 19 50 | 291 12 | | 30 52 | | 267 53 | | 260 53 | 45 |
| 20 | 335 55 | | 22 21 | 293 42 | | 33 22 | | 270 23 | | 263 18 | 45 |
| 30 | 338 25 | · · | 24 51 | 296 12 | · · | 35 52 | · · | 272 53 | · · | 265 43 | · 44 |
| 40 | 340 55 | | 27 22 | 298 42 | | 38 22 | | 275 24 | | 268 08 | 44 |
| 50 | 343 25 | | 29 52 | 301 12 | | 40 52 | | 277 54 | | 270 34 | 43 |
| 11 00 | 345 55 | N17 27 | 32 22 | 303 42 | N25 38 | 43 22 | S 6 30 | 280 24 | N22 20 | 272 59 | N18 43 |
| 10 | 348 25 | | 34 53 | 306 12 | | 45 52 | | 282 55 | | 275 24 | 42 |
| 20 | 350 55 | | 37 23 | 308 41 | | 48 22 | | 285 25 | | 277 49 | 41 |
| 30 | 353 25 | · · | 39 54 | 311 11 | · · | 50 53 | · · | 287 55 | · · | 280 15 | · 41 |
| 40 | 355 55 | | 42 24 | 313 41 | | 53 23 | | 290 26 | | 282 40 | 40 |
| 50 | 358 25 | | 44 54 | 316 11 | | 55 53 | | 292 56 | | 285 05 | 40 |
| 12 00 | 0 55 | N17 28 | 47 25 | 318 41 | N25 38 | 58 23 | S 6 29 | 295 26 | N22 20 | 287 30 | N18 39 |

☾ Par.

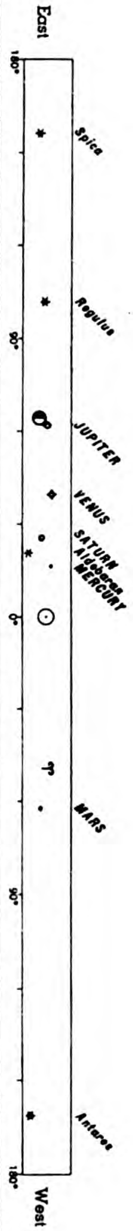
| Alt. ° | Corr. + ′ |
|---|---|
| 0 | |
| 9 | 54 |
| 14 | 53 |
| 18 | 52 |
| 21 | 51 |
| 24 | 50 |
| 26 | 49 |
| 28 | 48 |
| 30 | 47 |
| 32 | 46 |
| 34 | 45 |
| 36 | 44 |
| 38 | 43 |
| 40 | 42 |
| 41 | 41 |
| 43 | 40 |
| 44 | 39 |
| 46 | 38 |
| 47 | 37 |
| 49 | 36 |
| 50 | 35 |
| 51 | 34 |
| 53 | 33 |
| 54 | 32 |
| 55 | 31 |
| 57 | 30 |
| 58 | 29 |
| 59 | 28 |
| 60 | 27 |
| 61 | 26 |
| 63 | 25 |
| 64 | 24 |
| 65 | 23 |
| 66 | 22 |
| 67 | 21 |
| 68 | 20 |
| 70 | 19 |
| 71 | 18 |
| 72 | 17 |
| 73 | 16 |
| 74 | 15 |
| 75 | 14 |
| 76 | 13 |
| 77 | 12 |
| 78 | 11 |
| 79 | 10 |

SD, ☉ ′ 16

SD, ☾ ′ 15

Corr. HA ☾

| Int. m | Corr. ′ |
|---|---|
| 0 | 0 |
| 10 | |



## GREENWICH P. M. 1943 MAY 10 (MONDAY)

| GCT h | GCT m | ☉ SUN GHA | SUN Dec. | ♈ GHA | VENUS – 3.6 GHA | VENUS Dec. | MARS 0.9 GHA | MARS Dec. | JUPITER – 1.5 GHA | JUPITER Dec. | ◐ MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| h | m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 | 00 | 0 55 | N17 28 | 47 25 | 318 41 | N25 38 | 58 23 | S 6 29 | 295 26 | N22 20 | 287 30 | N18 39 |
| | 10 | 3 25 | | 49 55 | 321 11 | | 60 53 | | 297 57 | | 289 56 | 39 |
| | 20 | 5 55 | | 52 26 | 323 41 | | 63 23 | | 300 27 | | 292 21 | 38 |
| | 30 | 8 25 | · · | 54 56 | 326 11 | · · | 65 53 | · · | 302 57 | · · | 294 46 | · 37 |
| | 40 | 10 55 | | 57 26 | 328 40 | | 68 23 | | 305 28 | | 297 11 | 37 |
| | 50 | 13 25 | | 59 57 | 331 10 | | 70 54 | | 307 58 | | 299 37 | 36 |
| 13 | 00 | 15 55 | N17 28 | 62 27 | 333 40 | N25 38 | 73 24 | S 6 28 | 310 28 | N22 20 | 302 02 | N18 36 |
| | 10 | 18 25 | | 64 58 | 336 10 | | 75 54 | | 312 59 | | 304 27 | 35 |
| | 20 | 20 55 | | 67 28 | 338 40 | | 78 24 | | 315 29 | | 306 52 | 34 |
| | 30 | 23 25 | · · | 69 59 | 341 10 | · · | 80 54 | · · | 317 59 | · · | 309 18 | · 34 |
| | 40 | 25 55 | | 72 29 | 343 40 | | 83 24 | | 320 30 | | 311 43 | 33 |
| | 50 | 28 25 | | 74 59 | 346 10 | | 85 54 | | 323 00 | | 314 08 | 33 |
| 14 | 00 | 30 55 | N17 29 | 77 30 | 348 40 | N25 38 | 88 24 | S 6 28 | 325 30 | N22 20 | 316 33 | N18 32 |
| | 10 | 33 25 | | 80 00 | 351 09 | | 90 55 | | 328 01 | | 318 59 | 31 |
| | 20 | 35 55 | | 82 31 | 353 39 | | 93 25 | | 330 31 | | 321 24 | 31 |
| | 30 | 38 25 | · · | 85 01 | 356 09 | · · | 95 55 | · · | 333 01 | · · | 323 49 | · 30 |
| | 40 | 40 55 | | 87 31 | 358 39 | | 98 25 | | 335 32 | | 326 14 | 30 |
| | 50 | 43 25 | | 90 02 | 1 09 | | 100 55 | | 338 02 | | 328 40 | 29 |
| 15 | 00 | 45 55 | N17 30 | 92 32 | 3 39 | N25 38 | 103 25 | S 6 27 | 340 32 | N22 20 | 331 05 | N18 28 |
| | 10 | 48 25 | | 95 03 | 6 09 | | 105 55 | | 343 03 | | 333 30 | 28 |
| | 20 | 50 55 | | 97 33 | 8 39 | | 108 25 | | 345 33 | | 335 55 | 27 |
| | 30 | 53 25 | · · | 100 03 | 11 08 | · · | 110 55 | · · | 348 03 | · · | 338 21 | · 26 |
| | 40 | 55 55 | | 102 34 | 13 38 | | 113 26 | | 350 34 | | 340 46 | 26 |
| | 50 | 58 25 | | 105 04 | 16 08 | | 115 56 | | 353 04 | | 343 11 | 25 |
| 16 | 00 | 60 55 | N17 30 | 107 35 | 18 38 | N25 38 | 118 26 | S 6 26 | 355 35 | N22 19 | 345 36 | N18 25 |
| | 10 | 63 25 | | 110 05 | 21 08 | | 120 56 | | 358 05 | | 348 02 | 24 |
| | 20 | 65 55 | | 112 35 | 23 38 | | 123 26 | | 0 35 | | 350 27 | 23 |
| | 30 | 68 25 | · · | 115 06 | 26 08 | · · | 125 56 | · · | 3 06 | · · | 352 52 | · 23 |
| | 40 | 70 55 | | 117 36 | 28 38 | | 128 26 | | 5 36 | | 355 17 | 22 |
| | 50 | 73 25 | | 120 07 | 31 07 | | 130 56 | | 8 06 | | 357 43 | 21 |
| 17 | 00 | 75 55 | N17 31 | 122 37 | 33 37 | N25 38 | 133 27 | S 6 25 | 10 37 | N22 19 | 0 08 | N18 21 |
| | 10 | 78 25 | | 125 08 | 36 07 | | 135 57 | | 13 07 | | 2 33 | 20 |
| | 20 | 80 55 | | 127 38 | 38 37 | | 138 27 | | 15 37 | | 4 58 | 19 |
| | 30 | 83 25 | · · | 130 08 | 41 07 | · · | 140 57 | · · | 18 08 | · · | 7 24 | · 19 |
| | 40 | 85 55 | | 132 39 | 43 37 | | 143 27 | | 20 38 | | 9 49 | 18 |
| | 50 | 88 25 | | 135 09 | 46 07 | | 145 57 | | 23 08 | | 12 14 | 17 |
| 18 | 00 | 90 55 | N17 32 | 137 40 | 48 37 | N25 39 | 148 27 | S 6 25 | 25 39 | N22 19 | 14 39 | N18 17 |
| | 10 | 93 25 | | 140 10 | 51 07 | | 150 57 | | 28 09 | | 17 05 | 16 |
| | 20 | 95 55 | | 142 40 | 53 36 | | 153 28 | | 30 39 | | 19 30 | 15 |
| | 30 | 98 25 | · · | 145 11 | 56 06 | · · | 155 58 | · · | 33 10 | · · | 21 55 | · 15 |
| | 40 | 100 55 | | 147 41 | 58 36 | | 158 28 | | 35 40 | | 24 20 | 14 |
| | 50 | 103 25 | | 150 12 | 61 06 | | 160 58 | | 38 10 | | 26 46 | 13 |
| 19 | 00 | 105 55 | N17 32 | 152 42 | 63 36 | N25 39 | 163 28 | S 6 24 | 40 41 | N22 19 | 29 11 | N18 13 |
| | 10 | 108 25 | | 155 12 | 66 06 | | 165 58 | | 43 11 | | 31 36 | 12 |
| | 20 | 110 55 | | 157 43 | 68 36 | | 168 28 | | 45 41 | | 34 02 | 11 |
| | 30 | 113 25 | · · | 160 13 | 71 06 | · · | 170 58 | · · | 48 12 | · · | 36 27 | · 11 |
| | 40 | 115 55 | | 162 44 | 73 35 | | 173 28 | | 50 42 | | 38 52 | 10 |
| | 50 | 118 25 | | 165 14 | 76 05 | | 175 59 | | 53 12 | | 41 17 | 09 |
| 20 | 00 | 120 55 | N17 33 | 167 45 | 78 35 | N25 39 | 178 29 | S 6 23 | 55 43 | N22 19 | 43 43 | N18 09 |
| | 10 | 123 25 | | 170 15 | 81 05 | | 180 59 | | 58 13 | | 46 08 | 08 |
| | 20 | 125 55 | | 172 45 | 83 35 | | 183 29 | | 60 43 | | 48 33 | 07 |
| | 30 | 128 25 | · · | 175 16 | 86 05 | · · | 185 59 | · · | 63 14 | · · | 50 58 | · 07 |
| | 40 | 130 55 | | 177 46 | 88 35 | | 188 29 | | 65 44 | | 53 24 | 06 |
| | 50 | 133 25 | | 180 17 | 91 05 | | 190 59 | | 68 14 | | 55 49 | 05 |
| 21 | 00 | 135 55 | N17 34 | 182 47 | 93 35 | N25 39 | 193 29 | S 6 23 | 70 45 | N22 19 | 58 14 | N18 04 |
| | 10 | 138 25 | | 185 17 | 96 04 | | 196 00 | | 73 15 | | 60 40 | 04 |
| | 20 | 140 55 | | 187 48 | 98 34 | | 198 30 | | 75 45 | | 63 05 | 03 |
| | 30 | 143 25 | · · | 190 18 | 101 04 | · · | 201 00 | · · | 78 16 | · · | 65 30 | · 02 |
| | 40 | 145 55 | | 192 49 | 103 34 | | 203 30 | | 80 46 | | 67 55 | 02 |
| | 50 | 148 25 | | 195 19 | 106 04 | | 206 00 | | 83 16 | | 70 21 | 01 |
| 22 | 00 | 150 55 | N17 34 | 197 49 | 108 34 | N25 39 | 208 30 | S 6 22 | 85 47 | N22 19 | 72 46 | N18 00 |
| | 10 | 153 25 | | 200 20 | 111 04 | | 211 00 | | 88 17 | | 75 11 | 17 59 |
| | 20 | 155 55 | | 202 50 | 113 34 | | 213 30 | | 90 47 | | 77 36 | 59 |
| | 30 | 158 25 | · · | 205 21 | 116 03 | · · | 216 01 | · · | 93 18 | · · | 80 02 | · 58 |
| | 40 | 160 55 | | 207 51 | 118 33 | | 218 31 | | 95 48 | | 82 27 | 57 |
| | 50 | 163 25 | | 210 21 | 121 03 | | 221 01 | | 98 18 | | 84 52 | 56 |
| 23 | 00 | 165 55 | N17 35 | 212 52 | 123 33 | N25 39 | 223 31 | S 6 21 | 100 49 | N22 19 | 87 18 | N17 56 |
| | 10 | 168 25 | | 215 22 | 126 03 | | 226 01 | | 103 19 | | 89 43 | 55 |
| | 20 | 170 55 | | 217 53 | 128 33 | | 228 31 | | 105 50 | | 92 08 | 54 |
| | 30 | 173 25 | · · | 220 23 | 131 03 | · · | 231 01 | · · | 108 20 | · · | 94 33 | · 54 |
| | 40 | 175 55 | | 222 54 | 133 33 | | 233 31 | | 110 50 | | 96 59 | 53 |
| | 50 | 178 25 | | 225 24 | 136 02 | | 236 02 | | 113 21 | | 99 24 | 52 |
| 24 | 00 | 180 55 | N17 36 | 227 54 | 138 32 | N25 39 | 238 32 | S 6 20 | 115 51 | N22 19 | 101 49 | N17 51 |

| Lat. | Sunrise h | Sunrise m | Twil. m | Moonrise h | Moonrise m | Diff. m |
|---|---|---|---|---|---|---|
| N ° | | | | | | |
| 70 | 1 | 38 | //// | 5 | 57 | 97 |
| 68 | 2 | 18 | //// | 6 | 49 | 80 |
| 66 | 2 | 46 | 114 | 7 | 21 | 73 |
| 64 | 3 | 06 | 80 | 7 | 45 | 69 |
| 62 | | 23 | 67 | 8 | 03 | 66 |
| 60 | | 37 | 61 | | 19 | 63 |
| 58 | | 49 | 54 | | 32 | 62 |
| 56 | 3 | 59 | 49 | | 43 | 60 |
| 54 | 4 | 08 | 45 | 8 | 53 | 59 |
| 52 | | 16 | 41 | 9 | 02 | 58 |
| 50 | | 23 | 39 | | 10 | 57 |
| 45 | | 38 | 34 | | 26 | 55 |
| 40 | 4 | 51 | 31 | | 40 | 54 |
| 35 | 5 | 01 | 28 | 9 | 51 | 53 |
| 30 | | 11 | 26 | 10 | 01 | 52 |
| 20 | | 26 | 24 | | 19 | 49 |
| 10 | | 40 | 22 | | 34 | 48 |
| 0 | 5 | 53 | 22 | 10 | 48 | 47 |
| 10 | 6 | 05 | 22 | 11 | 02 | 46 |
| 20 | | 18 | 23 | | 17 | 44 |
| 30 | | 34 | 24 | | 35 | 41 |
| 35 | | 43 | 26 | | 45 | 40 |
| 40 | 6 | 52 | 28 | 11 | 56 | 40 |
| 45 | 7 | 04 | 31 | 12 | 10 | 38 |
| 50 | | 18 | 35 | | 26 | 36 |
| 52 | | 25 | 36 | | 34 | 35 |
| 54 | | 32 | 38 | | 42 | 34 |
| 56 | | 40 | 40 | 12 | 52 | 32 |
| 58 | 7 | 49 | 43 | 13 | 03 | 31 |
| 60 | 8 | 00 | 47 | 13 | 16 | 29 |
| S | | | | | | |

| Lat. | Sunset h | Sunset m | Twil. m | Moonset h | Moonset m | Diff. m |
|---|---|---|---|---|---|---|
| N ° | | | | | | |
| 70 | 22 | 21 | //// | 3 | 19 | 01 |
| 68 | 21 | 38 | //// | 2 | 27 | 17 |
| 66 | 21 | 10 | 121 | 1 | 55 | 24 |
| 64 | 20 | 49 | 82 | | 31 | 28 |
| 62 | | 32 | 68 | 1 | 12 | 31 |
| 60 | | 17 | 60 | 0 | 56 | 33 |
| 58 | 20 | 05 | 52 | | 43 | 35 |
| 56 | 19 | 55 | 47 | | 32 | 36 |
| 54 | | 46 | 44 | | 22 | 37 |
| 52 | | 38 | 41 | | 13 | 38 |
| 50 | | 30 | 38 | 0 | 05 | 39 |
| 45 | | 15 | 34 | 24 | 28 | 36 |
| 40 | 19 | 02 | 30 | | 15 | 38 |
| 35 | 18 | 52 | 27 | 24 | 04 | 40 |
| 30 | | 42 | 25 | 23 | 55 | 40 |
| 20 | | 26 | 23 | | 39 | 42 |
| 10 | | 13 | 22 | | 24 | 45 |
| 0 | 18 | 00 | 22 | 23 | 11 | 46 |
| 10 | 17 | 47 | 22 | 22 | 57 | 48 |
| 20 | | 33 | 23 | | 43 | 50 |
| 30 | | 18 | 25 | | 26 | 52 |
| 35 | 17 | 09 | 27 | | 16 | 54 |
| 40 | 16 | 59 | 29 | 22 | 05 | 55 |
| 45 | | 48 | 32 | 21 | 52 | 57 |
| 50 | | 33 | 35 | | 36 | 59 |
| 52 | | 27 | 37 | | 29 | 60 |
| 54 | | 20 | 39 | | 20 | 62 |
| 56 | | 11 | 41 | | 11 | 63 |
| 58 | 16 | 02 | 44 | 21 | 00 | 65 |
| 60 | 15 | 52 | 48 | 20 | 48 | 66 |
| S | | | | | | |



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UNIVERSITY OF WISCONSIN

## GREENWICH A. M. 1943 MAY 15 (SATURDAY)

| GCT | ⊙ SUN GHA | Dec. | ♈ GHA | VENUS − 3.6 GHA | Dec. | MARS 0.9 GHA | Dec. | JUPITER − 1.5 GHA | Dec. | ☾ MOON GHA | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| **0 00** | 180 56 | N18 36 | 231 51 | 137 25 | N25 42 | 239 41 | S 5 12 | 119 06 | N22 13 | 57 54 | N 5 32 |
| 10 | 183 26 | | 234 21 | 139 55 | | 242 11 | | 121 37 | | 60 20 | 30 |
| 20 | 185 56 | | 236 52 | 142 24 | | 244 41 | | 124 07 | | 62 45 | 28 |
| 30 | 188 26 | · · | 239 22 | 144 54 | · · | 247 11 | · · | 126 37 | · · | 65 11 | · 27 |
| 40 | 190 56 | | 241 53 | 147 24 | | 249 41 | | 129 08 | | 67 36 | 25 |
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| **1 00** | 195 56 | N18 37 | 246 53 | 152 24 | N25 42 | 254 42 | S 5 11 | 134 08 | N22 13 | 72 27 | N 5 22 |
| 10 | 198 26 | | 249 24 | 154 54 | | 257 12 | | 136 39 | | 74 52 | 20 |
| 20 | 200 56 | | 251 54 | 157 24 | | 259 42 | | 139 09 | | 77 18 | 18 |
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| **2 00** | 210 56 | N18 37 | 261 56 | 167 23 | N25 42 | 269 42 | S 5 10 | 149 10 | N22 13 | 87 00 | N 5 11 |
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| 20 | 215 56 | | 266 57 | 172 23 | | 274 43 | | 154 11 | | 91 51 | 08 |
| 30 | 218 26 | · · | 269 27 | 174 53 | · · | 277 13 | · · | 156 41 | · · | 94 16 | · 06 |
| 40 | 220 56 | | 271 57 | 177 23 | | 279 43 | | 159 12 | | 96 41 | 04 |
| 50 | 223 26 | | 274 28 | 179 53 | | 282 13 | | 161 42 | | 99 07 | 03 |
| **3 00** | 225 56 | N18 38 | 276 58 | 182 23 | N25 41 | 284 43 | S 5 09 | 164 13 | N22 13 | 101 32 | N 5 01 |
| 10 | 228 26 | | 279 29 | 184 53 | | 287 13 | | 166 43 | | 103 58 | 4 59 |
| 20 | 230 56 | | 281 59 | 187 22 | | 289 43 | | 169 13 | | 106 23 | 57 |
| 30 | 233 26 | · · | 284 30 | 189 52 | · · | 292 14 | · · | 171 44 | · · | 108 49 | · 56 |
| 40 | 235 56 | | 287 00 | 192 22 | | 294 44 | | 174 14 | | 111 14 | 54 |
| 50 | 238 26 | | 289 30 | 194 52 | | 297 14 | | 176 44 | | 113 40 | 52 |
| **4 00** | 240 56 | N18 39 | 292 01 | 197 22 | N25 41 | 299 44 | S 5 09 | 179 15 | N22 13 | 116 05 | N 4 51 |
| 10 | 243 26 | | 294 31 | 199 52 | | 302 14 | | 181 45 | | 118 30 | 49 |
| 20 | 245 56 | | 297 02 | 202 22 | | 304 44 | | 184 15 | | 120 56 | 47 |
| 30 | 248 26 | · · | 299 32 | 204 52 | · · | 307 14 | · · | 186 46 | · · | 123 21 | · 45 |
| 40 | 250 56 | | 302 02 | 207 21 | | 309 44 | | 189 16 | | 125 47 | 44 |
| 50 | 253 26 | | 304 33 | 209 51 | | 312 14 | | 191 46 | | 128 12 | 42 |
| **5 00** | 255 56 | N18 39 | 307 03 | 212 21 | N25 41 | 314 45 | S 5 08 | 194 17 | N22 13 | 130 38 | N 4 40 |
| 10 | 258 26 | | 309 34 | 214 51 | | 317 15 | | 196 47 | | 133 03 | 38 |
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| 50 | 268 26 | | 319 35 | 224 51 | | 327 15 | | 206 48 | | 142 45 | 32 |
| **6 00** | 270 56 | N18 40 | 322 06 | 227 21 | N25 41 | 329 45 | S 5 07 | 209 19 | N22 13 | 145 10 | N 4 30 |
| 10 | 273 26 | | 324 36 | 229 50 | | 332 15 | | 211 49 | | 147 36 | 28 |
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| 30 | 278 26 | · · | 329 37 | 234 50 | · · | 337 16 | · · | 216 50 | · · | 152 27 | · 25 |
| 40 | 280 56 | | 332 07 | 237 20 | | 339 46 | | 219 20 | | 154 52 | 23 |
| 50 | 283 26 | | 334 38 | 239 50 | | 342 16 | | 221 50 | | 157 17 | 21 |
| **7 00** | 285 56 | N18 40 | 337 08 | 242 20 | N25 41 | 344 46 | S 5 07 | 224 21 | N22 13 | 159 43 | N 4 19 |
| 10 | 288 26 | | 339 39 | 244 50 | | 347 16 | | 226 51 | | 162 08 | 18 |
| 20 | 290 56 | | 342 09 | 247 20 | | 349 46 | | 229 21 | | 164 34 | 16 |
| 30 | 293 26 | · · | 344 39 | 249 50 | · · | 352 16 | · · | 231 52 | · · | 166 59 | · 14 |
| 40 | 295 56 | | 347 10 | 252 19 | | 354 47 | | 234 22 | | 169 25 | 12 |
| 50 | 298 26 | | 349 40 | 254 49 | | 357 17 | | 236 52 | | 171 50 | 11 |
| **8 00** | 300 56 | N18 41 | 352 11 | 257 19 | N25 41 | 359 47 | S 5 06 | 239 23 | N22 13 | 174 16 | N 4 09 |
| 10 | 303 26 | | 354 41 | 259 49 | | 2 17 | | 241 53 | | 176 41 | 07 |
| 20 | 305 56 | | 357 11 | 262 19 | | 4 47 | | 244 23 | | 179 06 | 05 |
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| **9 00** | 315 56 | N18 42 | 7 13 | 272 19 | N25 41 | 14 48 | S 5 05 | 254 25 | N22 13 | 188 48 | N 3 58 |
| 10 | 318 26 | | 9 44 | 274 48 | | 17 18 | | 256 55 | | 191 13 | 57 |
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| 20 | 335 56 | | 27 16 | 292 18 | | 34 49 | | 274 27 | | 208 11 | 44 |
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| **11 00** | 345 56 | N18 43 | 37 18 | 302 17 | N25 41 | 44 49 | S 5 04 | 284 29 | N22 13 | 217 53 | N 3 37 |
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| 20 | 350 56 | | 42 19 | 307 17 | | 49 49 | | 289 29 | | 222 44 | 34 |
| 30 | 353 26 | · · | 44 49 | 309 47 | · · | 52 19 | · · | 292 00 | · · | 225 09 | · 32 |
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| **12 00** | 0 57 | N18 43 | 52 21 | 317 16 | N25 41 | 59 50 | S 5 03 | 299 31 | N22 13 | 232 26 | N 3 27 |

☾ Par.

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| 79 | 11 |
| 80 | 10 |

SD ⊙ ′ 16

SD ☾ ′ 15

Corr. HA ☾

| Int. m | Corr. ′ |
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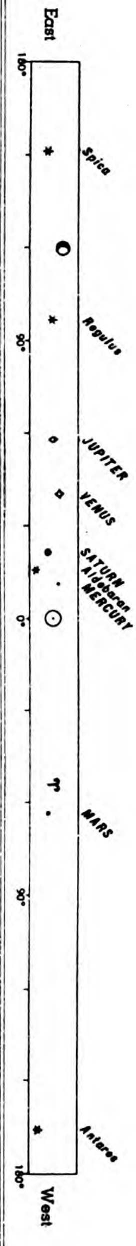




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## GREENWICH P. M. 1943 MAY 15 (SATURDAY)

| GCT | ☉ SUN GHA | SUN Dec. | ♈ GHA | VENUS –3.6 GHA | VENUS Dec. | MARS 0.9 GHA | MARS Dec. | JUPITER –1.5 GHA | JUPITER Dec. | ☾ MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| **12 00** | 0 57 | N18 43 | 52 21 | 317 16 | N25 41 | 59 50 | S 5 03 | 299 31 | N22 13 | 232 26 | N 3 27 |
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| 20 | 5 57 | | 57 21 | 322 16 | | 64 50 | | 304 31 | | 237 16 | 23 |
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| 50 | 13 27 | | 64 53 | 329 46 | | 72 20 | | 312 02 | | 244 33 | 18 |
| **13 00** | 15 57 | N18 44 | 67 23 | 332 16 | N25 41 | 74 50 | S 5 02 | 314 33 | N22 13 | 246 58 | N 3 16 |
| 10 | 18 27 | | 69 53 | 334 46 | | 77 21 | | 317 03 | | 249 24 | 14 |
| 20 | 20 57 | | 72 24 | 337 16 | | 79 51 | | 319 33 | | 251 49 | 12 |
| 30 | 23 27 · | · | 74 54 | 339 45 · | · | 82 21 · | · | 322 04 · | · | 254 14 · | 11 |
| 40 | 25 57 | | 77 25 | 342 15 | | 84 51 | | 324 34 | | 256 40 | 09 |
| 50 | 28 27 | | 79 55 | 344 45 | | 87 21 | | 327 04 | | 259 05 | 07 |
| **14 00** | 30 57 | N18 45 | 82 25 | 347 15 | N25 41 | 89 51 | S 5 02 | 329 35 | N22 13 | 261 31 | N 3 05 |
| 10 | 33 27 | | 84 56 | 349 45 | | 92 21 | | 332 05 | | 263 56 | 04 |
| 20 | 35 57 | | 87 26 | 352 15 | | 94 51 | | 334 35 | | 266 21 | 02 |
| 30 | 38 27 · | · | 89 57 | 354 45 · | · | 97 22 · | · | 337 06 · | · | 268 47 · | 3 00 |
| 40 | 40 57 | | 92 27 | 357 15 | | 99 52 | | 339 36 | | 271 12 | 2 58 |
| 50 | 43 27 | | 94 57 | 359 45 | | 102 22 | | 342 06 | | 273 38 | 56 |
| **15 00** | 45 57 | N18 45 | 97 28 | 2 14 | N25 41 | 104 52 | S 5 01 | 344 37 | N22 12 | 276 03 | N 2 55 |
| 10 | 48 27 | | 99 58 | 4 44 | | 107 22 | | 347 07 | | 278 28 | 53 |
| 20 | 50 57 | | 102 29 | 7 14 | | 109 52 | | 349 38 | | 280 54 | 51 |
| 30 | 53 27 · | · | 104 59 | 9 44 · | · | 112 22 · | · | 352 08 · | · | 283 19 · | 49 |
| 40 | 55 57 | | 107 30 | 12 14 | | 114 52 | | 354 38 | | 285 45 | 48 |
| 50 | 58 27 | | 110 00 | 14 44 | | 117 23 | | 357 09 | | 288 10 | 46 |
| **16 00** | 60 57 | N18 46 | 112 30 | 17 14 | N25 41 | 119 53 | S 5 00 | 359 39 | N22 12 | 290 35 | N 2 44 |
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| 30 | 68 27 · | · | 120 02 | 24 43 · | · | 127 23 · | · | 7 10 · | · | 297 52 · | 39 |
| 40 | 70 57 | | 122 32 | 27 13 | | 129 53 | | 9 40 | | 300 17 | 37 |
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| **17 00** | 75 57 | N18 46 | 127 33 | 32 13 | N25 41 | 134 53 | S 4 59 | 14 41 | N22 12 | 305 08 | N 2 33 |
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| 30 | 83 27 · | · | 135 04 | 39 43 · | · | 142 24 · | · | 22 12 · | · | 312 24 · | 28 |
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| 30 | 98 27 · | · | 150 07 | 54 42 · | · | 157 25 · | · | 37 14 · | · | 326 56 · | 17 |
| 40 | 100 57 | | 152 37 | 57 12 | | 159 55 | | 39 44 | | 329 22 | 15 |
| 50 | 103 27 | | 155 07 | 59 42 | | 162 25 | | 42 15 | | 331 47 | 14 |
| **19 00** | 105 57 | N18 48 | 157 38 | 62 12 | N25 41 | 164 55 | S 4 58 | 44 45 | N22 12 | 334 12 | N 2 12 |
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| 20 | 110 57 | | 162 39 | 67 12 | | 169 55 | | 49 46 | | 339 03 | 08 |
| 30 | 113 27 · | · | 165 09 | 69 41 · | · | 172 25 · | · | 52 16 · | · | 341 29 · | 06 |
| 40 | 115 57 | | 167 39 | 72 11 | | 174 55 | | 54 46 | | 343 54 | 05 |
| 50 | 118 27 | | 170 10 | 74 41 | | 177 26 | | 57 17 | | 346 19 | 03 |
| **20 00** | 120 57 | N18 48 | 172 40 | 77 11 | N25 41 | 179 56 | S 4 57 | 59 47 | N22 12 | 348 45 | N 2 01 |
| 10 | 123 27 | | 175 11 | 79 41 | | 182 26 | | 62 17 | | 351 10 | 1 59 |
| 20 | 125 57 | | 177 41 | 82 11 | | 184 56 | | 64 48 | | 353 35 | 57 |
| 30 | 128 27 · | · | 180 11 | 84 41 · | · | 187 26 · | · | 67 18 · | · | 356 01 · | 56 |
| 40 | 130 57 | | 182 42 | 87 11 | | 189 56 | | 69 48 | | 358 26 | 54 |
| 50 | 133 27 | | 185 12 | 89 40 | | 192 26 | | 72 19 | | 0 52 | 52 |
| **21 00** | 135 57 | N18 49 | 187 43 | 92 10 | N25 41 | 194 56 | S 4 57 | 74 49 | N22 12 | 3 17 | N 1 50 |
| 10 | 138 27 | | 190 13 | 94 40 | | 197 26 | | 77 19 | | 5 42 | 48 |
| 20 | 140 57 | | 192 44 | 97 10 | | 199 57 | | 79 50 | | 8 08 | 46 |
| 30 | 143 27 · | · | 195 14 | 99 40 · | · | 202 27 · | · | 82 20 · | · | 10 33 · | 45 |
| 40 | 145 57 | | 197 44 | 102 10 | | 204 57 | | 84 50 | | 12 58 | 43 |
| 50 | 148 27 | | 200 15 | 104 40 | | 207 27 | | 87 21 | | 15 24 | 41 |
| **22 00** | 150 57 | N18 49 | 202 45 | 107 10 | N25 41 | 209 57 | S 4 56 | 89 51 | N22 12 | 17 49 | N 1 39 |
| 10 | 153 27 | | 205 16 | 109 40 | | 212 27 | | 92 21 | | 20 15 | 37 |
| 20 | 155 57 | | 207 46 | 112 09 | | 214 57 | | 94 52 | | 22 40 | 36 |
| 30 | 158 27 · | · | 210 16 | 114 39 · | · | 217 27 · | · | 97 22 · | · | 25 05 · | 34 |
| 40 | 160 57 | | 212 47 | 117 09 | | 219 58 | | 99 52 | | 27 31 | 32 |
| 50 | 163 27 | | 215 17 | 119 39 | | 222 28 | | 102 23 | | 29 56 | 30 |
| **23 00** | 165 57 | N18 50 | 217 48 | 122 09 | N25 41 | 224 58 | S 4 55 | 104 53 | N22 12 | 32 21 | N 1 28 |
| 10 | 168 27 | | 220 18 | 124 39 | | 227 28 | | 107 23 | | 34 47 | 26 |
| 20 | 170 57 | | 222 48 | 127 09 | | 229 58 | | 109 54 | | 37 12 | 25 |
| 30 | 173 27 · | · | 225 19 | 129 39 · | · | 232 28 · | · | 112 24 · | · | 39 38 · | 23 |
| 40 | 175 57 | | 227 49 | 132 09 | | 234 58 | | 114 54 | | 42 03 | 21 |
| 50 | 178 27 | | 230 20 | 134 38 | | 237 28 | | 117 25 | | 44 28 | 19 |
| **24 00** | 180 57 | N18 51 | 232 50 | 137 08 | N25 41 | 239 59 | S 4 54 | 119 55 | N22 12 | 46 54 | N 1 17 |

| Lat. | Sun-rise | Twlt. | Moon-rise | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | 0 53 | //// | 14 02 | 99 |
| 68 | 1 52 | //// | 05 | 94 |
| 66 | 2 26 | //// | 08 | 89 |
| 64 | 2 50 | 95 | 10 | 86 |
| 62 | 3 09 | 73 | 12 | 82 |
| 60 | 25 | 65 | 14 | 79 |
| 58 | 38 | 56 | 16 | 76 |
| 56 | 49 | 51 | 17 | 75 |
| 54 | 3 59 | 47 | 18 | 73 |
| 52 | 4 08 | 43 | 20 | 70 |
| 50 | 16 | 40 | 21 | 69 |
| 45 | 32 | 35 | 23 | 65 |
| 40 | 46 | 32 | 25 | 62 |
| 35 | 4 57 | 29 | 27 | 59 |
| 30 | 5 07 | 26 | 28 | 58 |
| 20 | 24 | 24 | 31 | 53 |
| 10 | 39 | 23 | 33 | 50 |
| 0 | 5 53 | 22 | 36 | 46 |
| 10 | 6 06 | 22 | 38 | 43 |
| 20 | 21 | 23 | 40 | 40 |
| 30 | 37 | 25 | 42 | 36 |
| 35 | 46 | 27 | 44 | 34 |
| 40 | 6 57 | 29 | 46 | 31 |
| 45 | 7 10 | 31 | 48 | 28 |
| 50 | 25 | 36 | 50 | 25 |
| 52 | 33 | 37 | 51 | 23 |
| 54 | 40 | 39 | 52 | 22 |
| 56 | 49 | 42 | 54 | 19 |
| 58 | 7 59 | 44 | 55 | 17 |
| 60 | 8 11 | 48 | 14 57 | 15 |
| S | | | | |

| Lat. | Sun-set | Twlt. | Moon-set | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | 23 13 | //// | 3 09 | * |
| 68 | 22 05 | //// | 3 03 | 01 |
| 66 | 21 30 | //// | 2 58 | 06 |
| 64 | 21 05 | 98 | 54 | 09 |
| 62 | 20 46 | 74 | 51 | 12 |
| 60 | 29 | 64 | 48 | 14 |
| 58 | 16 | 55 | 45 | 17 |
| 56 | 20 04 | 50 | 43 | 19 |
| 54 | 19 54 | 46 | 40 | 21 |
| 52 | 46 | 42 | 39 | 22 |
| 50 | 38 | 39 | 37 | 24 |
| 45 | 21 | 34 | 33 | 27 |
| 40 | 19 07 | 31 | 30 | 30 |
| 35 | 18 56 | 28 | 27 | 32 |
| 30 | 46 | 26 | 24 | 35 |
| 20 | 28 | 24 | 20 | 38 |
| 10 | 14 | 22 | 16 | 42 |
| 0 | 18 00 | 22 | 12 | 45 |
| 10 | 17 46 | 23 | 08 | 49 |
| 20 | 31 | 24 | 04 | 52 |
| 30 | 15 | 25 | 2 00 | 56 |
| 35 | 17 05 | 27 | 1 57 | 58 |
| 40 | 16 54 | 29 | 54 | 61 |
| 45 | 41 | 32 | 50 | 64 |
| 50 | 26 | 36 | 46 | 67 |
| 52 | 19 | 38 | 44 | 69 |
| 54 | 11 | 40 | 42 | 70 |
| 56 | 16 02 | 43 | 39 | 73 |
| 58 | 15 51 | 45 | 36 | 76 |
| 60 | 15 39 | 49 | 1 34 | 77 |
| S | | | | |



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# GREENWICH A. M. 1943 MAY 20 (THURSDAY)

| GCT | ☉ SUN GHA | ☉ SUN Dec. | ♈ GHA | VENUS – 3.6 GHA | VENUS – 3.6 Dec. | MARS 0.9 GHA | MARS 0.9 Dec. | JUPITER – 1.5 GHA | JUPITER – 1.5 Dec. | ○ MOON GHA | ○ MOON Dec. |
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| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
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| 20 | 185 55 | | 241 47 | 141 04 | | 246 09 | | 128 10 | | 3 01 | 18 |
| 30 | 188 25 | · · | 244 18 | 143 34 | · · | 248 40 | · · | 130 40 | · · | 5 26 | · 19 |
| 40 | 190 55 | | 246 48 | 146 04 | | 251 10 | | 133 10 | | 7 50 | 21 |
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| 10 | 198 25 | | 254 19 | 153 33 | | 258 40 | | 140 41 | | 15 03 | 25 |
| 20 | 200 55 | | 256 50 | 156 03 | | 261 10 | | 143 12 | | 17 27 | 26 |
| 30 | 203 25 | · · | 259 20 | 158 33 | · · | 263 40 | · · | 145 42 | · · | 19 52 | · 27 |
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| 50 | 208 25 | | 264 21 | 163 33 | | 268 40 | | 150 43 | | 24 40 | 30 |
| 2 00 | 210 55 | N19 46 | 266 52 | 166 03 | N25 29 | 271 11 | S 3 44 | 153 13 | N22 06 | 27 05 | S15 31 |
| 10 | 213 25 | | 269 22 | 168 33 | | 273 41 | | 155 43 | | 29 29 | 33 |
| 20 | 215 55 | | 271 52 | 171 03 | | 276 11 | | 158 14 | | 31 54 | 34 |
| 30 | 218 25 | · · | 274 23 | 173 33 | · · | 278 41 | · · | 160 44 | · · | 34 18 | · 35 |
| 40 | 220 55 | | 276 53 | 176 02 | | 281 11 | | 163 14 | | 36 42 | 36 |
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| 3 00 | 225 55 | N19 46 | 281 54 | 181 02 | N25 29 | 286 11 | S 3 43 | 168 15 | N22 06 | 41 31 | S15 39 |
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| 5 00 | 255 55 | N19 47 | 311 59 | 211 01 | N25 29 | 316 13 | S 3 41 | 198 19 | N22 05 | 70 23 | S15 54 |
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| 50 | 268 25 | | 324 31 | 223 30 | | 328 43 | | 210 51 | | 82 24 | 16 00 |
| 6 00 | 270 55 | N19 48 | 327 01 | 226 00 | N25 28 | 331 14 | S 3 41 | 213 21 | N22 05 | 84 49 | S16 02 |
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| 8 00 | 300 55 | N19 49 | 357 06 | 255 59 | N25 28 | 1 15 | S 3 39 | 243 25 | N22 05 | 113 40 | S16 16 |
| 10 | 303 25 | | 359 37 | 258 29 | | 3 45 | | 245 55 | | 116 04 | 18 |
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| 20 | 320 55 | | 17 10 | 275 58 | | 21 16 | | 263 28 | | 132 54 | 26 |
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| 40 | 325 55 | | 22 10 | 280 58 | | 26 16 | | 268 28 | | 137 43 | 28 |
| 50 | 328 25 | | 24 41 | 283 28 | | 28 46 | | 270 59 | | 140 07 | 30 |
| 10 00 | 330 55 | N19 50 | 27 11 | 285 58 | N25 28 | 31 17 | S 3 38 | 273 29 | N22 05 | 142 32 | S16 31 |
| 10 | 333 25 | | 29 42 | 288 28 | | 33 47 | | 275 59 | | 144 56 | 32 |
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☾ Par.

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| 76 | 13 |
| 77 | 12 |
| 78 | 11 |
| 79 | 10 |
| 80 | |

SD, ☉ ′ 16

SD, ☾ ′ 16

Corr. HA ☾

| Int. m | Corr. ′ |
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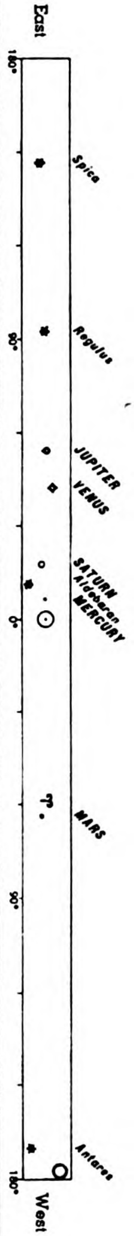




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## GREENWICH P. M. 1943 MAY 20 (THURSDAY)

| GCT | | ☉ SUN GHA | ☉ SUN Dec. | ♈ GHA | VENUS – 3.6 GHA | VENUS – 3.6 Dec. | MARS 0.9 GHA | MARS 0.9 Dec. | JUPITER – 1.5 GHA | JUPITER – 1.5 Dec. | ☾ MOON GHA | ☾ MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| h | m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 | 00 | 0 55 | N19 51 | 57 16 | 315 56 | N25 27 | 61 18 | S 3 36 | 303 33 | N22 05 | 171 22 | S16 45 |
| | 10 | 3 25 | | 59 47 | 318 26 | | 63 48 | | 306 03 | | 173 47 | 46 |
| | 20 | 5 55 | | 62 17 | 320 56 | | 66 18 | | 308 34 | | 176 11 | 47 |
| | 30 | 8 25 · | · | 64 47 | 323 26 · | · | 68 48 · | · | 311 04 · | · | 178 35 · | 48 |
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| | 50 | 13 25 | | 69 48 | 328 26 | | 73 49 | | 316 05 | | 183 24 | 50 |
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| | 20 | 20 55 | | 77 19 | 335 56 | | 81 19 | | 323 36 | | 190 36 | 54 |
| | 30 | 23 25 · | · | 79 50 | 338 25 · | · | 83 49 · | · | 326 06 · | · | 193 00 · | 55 |
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| | 50 | 28 25 | | 84 51 | 343 25 | | 88 49 | | 331 07 | | 197 49 | 57 |
| 14 | 00 | 30 55 | N19 52 | 87 21 | 345 55 | N25 27 | 91 20 | S 3 35 | 333 37 | N22 05 | 200 13 | S16 58 |
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| | 30 | 38 25 · | · | 94 52 | 353 25 · | · | 98 50 · | · | 341 08 · | · | 207 26 · | 01 |
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| | 50 | 43 25 | | 99 53 | 358 25 | | 103 50 | | 346 09 | | 212 14 | 03 |
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| | 30 | 53 25 · | · | 109 55 | 8 24 · | · | 113 51 · | · | 356 10 · | · | 221 51 · | 08 |
| | 40 | 55 55 | | 112 25 | 10 54 | | 116 21 | | 358 40 | | 224 15 | 09 |
| | 50 | 58 25 | | 114 56 | 13 24 | | 118 51 | | 1 11 | | 226 39 | 10 |
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| | 30 | 68 25 · | · | 124 57 | 23 24 · | · | 128 51 · | · | 11 12 · | · | 236 16 · | 14 |
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| | 50 | 73 25 | | 129 58 | 28 23 | | 133 52 | | 16 13 | | 241 05 | 16 |
| 17 | 00 | 75 55 | N19 54 | 132 29 | 30 53 | N25 26 | 136 22 | S 3 33 | 18 43 | N22 05 | 243 29 | S17 17 |
| | 10 | 78 25 | | 134 59 | 33 23 | | 138 52 | | 21 13 | | 245 53 | 18 |
| | 20 | 80 55 | | 137 29 | 35 53 | | 141 22 | | 23 44 | | 248 17 | 19 |
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| 19 | 00 | 105 54 | N19 55 | 162 33 | 60 52 | N25 26 | 166 23 | S 3 31 | 48 47 | N22 04 | 272 19 | S17 30 |
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| | 50 | 118 24 | | 175 06 | 73 21 | | 178 54 | | 61 19 | | 284 20 | 35 |
| 20 | 00 | 120 54 | N19 55 | 177 36 | 75 51 | N25 26 | 181 24 | S 3 31 | 63 49 | N22 04 | 286 44 | S17 36 |
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| | 20 | 125 54 | | 182 37 | 80 51 | | 186 24 | | 68 50 | | 291 32 | 38 |
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| | 40 | 130 54 | | 187 38 | 85 51 | | 191 25 | | 73 50 | | 296 20 | 40 |
| | 50 | 133 24 | | 190 08 | 88 21 | | 193 55 | | 76 21 | | 298 44 | 41 |
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| | 20 | 140 54 | | 197 39 | 95 50 | | 201 25 | | 83 52 | | 305 57 | 43 |
| | 30 | 143 24 · | · | 200 10 | 98 20 · | · | 203 55 · | · | 86 22 · | · | 308 21 · | 44 |
| | 40 | 145 54 | | 202 40 | 100 50 | | 206 25 | | 88 52 | | 310 45 | 45 |
| | 50 | 148 24 | | 205 10 | 103 20 | | 208 55 | | 91 23 | | 313 09 | 46 |
| 22 | 00 | 150 54 | N19 56 | 207 41 | 105 50 | N25 25 | 211 26 | S 3 29 | 93 53 | N22 04 | 315 34 | S17 47 |
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| | 20 | 155 54 | | 212 42 | 110 50 | | 216 26 | | 98 54 | | 320 22 | 49 |
| | 30 | 158 24 · | · | 215 12 | 113 20 · | · | 218 56 · | · | 101 24 · | · | 322 46 · | 50 |
| | 40 | 160 54 | | 217 42 | 115 50 | | 221 26 | | 103 54 | | 325 10 | 51 |
| | 50 | 163 24 | | 220 13 | 118 20 | | 223 56 | | 106 25 | | 327 34 | 52 |
| 23 | 00 | 165 54 | N19 57 | 222 43 | 120 49 | N25 25 | 226 26 | S 3 28 | 108 55 | N22 04 | 329 58 | S17 53 |
| | 10 | 168 24 | | 225 14 | 123 19 | | 228 56 | | 111 25 | | 332 22 | 54 |
| | 20 | 170 54 | | 227 44 | 125 49 | | 231 27 | | 113 56 | | 334 46 | 55 |
| | 30 | 173 24 · | · | 230 15 | 128 19 · | · | 233 57 · | · | 116 26 · | · | 337 11 · | 56 |
| | 40 | 175 54 | | 232 45 | 130 49 | | 236 27 | | 118 56 | | 339 35 | 57 |
| | 50 | 178 24 | | 235 15 | 133 19 | | 238 57 | | 121 27 | | 341 59 | 57 |
| 24 | 00 | 180 54 | N19 57 | 237 46 | 135 49 | N25 25 | 241 27 | S 3 28 | 123 57 | N22 04 | 344 23 | S17 58 |

| Lat. | Sun-rise | Twit. | Moon-rise | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | □ | □ | 23 15 | 133 |
| 68 | 1 22 | //// | 22 33 | 98 |
| 66 | 2 06 | //// | 22 05 | 88 |
| 64 | 34 | 125 | 21 44 | 83 |
| 62 | 2 56 | 82 | 26 | 80 |
| 60 | 3 13 | 69 | 12 | 77 |
| 58 | 28 | 60 | 21 00 | 75 |
| 56 | 40 | 54 | 20 49 | 74 |
| 54 | 3 51 | 48 | 40 | 73 |
| 52 | 4 00 | 45 | 32 | 71 |
| 50 | 09 | 42 | 24 | 71 |
| 45 | 27 | 36 | 20 08 | 69 |
| 40 | 41 | 32 | 19 56 | 67 |
| 35 | 4 54 | 29 | 45 | 65 |
| 30 | 5 04 | 27 | 35 | 65 |
| 20 | 22 | 24 | 19 | 62 |
| 10 | 38 | 23 | 19 04 | 61 |
| 0 | 5 53 | 22 | 18 51 | 59 |
| 10 | 6 08 | 22 | 38 | 58 |
| 20 | 23 | 24 | 24 | 56 |
| 30 | 40 | 25 | 18 08 | 54 |
| 35 | 6 50 | 27 | 17 59 | 52 |
| 40 | 7 02 | 29 | 48 | 52 |
| 45 | 15 | 32 | 36 | 49 |
| 50 | 32 | 36 | 21 | 47 |
| 52 | 39 | 38 | 14 | 46 |
| 54 | 48 | 40 | 17 06 | 45 |
| 56 | 7 57 | 43 | 16 58 | 43 |
| 58 | 8 08 | 46 | 48 | 42 |
| 60 | 8 21 | 50 | 16 37 | 39 |
| S | | | | |

| Lat. | Sun-set | Twit. | Moon-set | Diff. |
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| N ° | h m | m | h m | m |
| 70 | □ | □ | 2 49 | * |
| 68 | 22 36 | //// | 3 16 | 12 |
| 66 | 21 50 | //// | 36 | 21 |
| 64 | 21 21 | 141 | 3 53 | 26 |
| 62 | 20 59 | 84 | 4 06 | 31 |
| 60 | 40 | 69 | 18 | 34 |
| 58 | 26 | 59 | 28 | 36 |
| 56 | 14 | 52 | 37 | 38 |
| 54 | 20 03 | 47 | 45 | 40 |
| 52 | 19 53 | 43 | 52 | 41 |
| 50 | 44 | 40 | 4 58 | 43 |
| 45 | 26 | 35 | 5 12 | 45 |
| 40 | 12 | 31 | 23 | 48 |
| 35 | 19 00 | 28 | 33 | 49 |
| 30 | 18 49 | 26 | 41 | 52 |
| 20 | 30 | 24 | 5 56 | 54 |
| 10 | 15 | 23 | 6 09 | 56 |
| 0 | 18 00 | 22 | 21 | 58 |
| 10 | 17 46 | 23 | 33 | 60 |
| 20 | 31 | 24 | 6 46 | 62 |
| 30 | 13 | 26 | 7 01 | 66 |
| 35 | 17 03 | 28 | 10 | 66 |
| 40 | 16 51 | 30 | 19 | 68 |
| 45 | 38 | 32 | 31 | 70 |
| 50 | 21 | 36 | 45 | 73 |
| 52 | 13 | 38 | 52 | 74 |
| 54 | 16 05 | 41 | 7 59 | 75 |
| 56 | 15 55 | 44 | 8 07 | 77 |
| 58 | 44 | 46 | 16 | 79 |
| 60 | 15 31 | 51 | 8 27 | 81 |
| S | | | | |



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## GREENWICH A. M. 1943 MAY 25 (TUESDAY)

| GCT h m | ☉ SUN GHA ° ′ | Dec. ° ′ | ♈ GHA ° ′ | VENUS − 3.6 GHA ° ′ | Dec. ° ′ | MARS 0.9 GHA ° ′ | Dec. ° ′ | JUPITER − 1.5 GHA ° ′ | Dec. ° ′ | ◑ MOON GHA ° ′ | Dec. ° ′ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 00 | 180 50 | N20 45 | 241 42 | 134 50 | N25 01 | 242 39 | S 2 18 | 127 09 | N21 57 | 287 04 | S16 32 |
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| 20 | 185 50 | | 246 43 | 139 50 | | 247 39 | | 132 09 | | 291 53 | 30 |
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| 50 | 193 20 | | 254 14 | 147 20 | | 255 09 | | 139 40 | | 299 06 | 26 |
| 1 00 | 195 50 | N20 45 | 256 45 | 149 50 | N25 01 | 257 40 | S 2 17 | 142 11 | N21 57 | 301 30 | S16 25 |
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| 20 | 200 50 | | 261 46 | 154 50 | | 262 40 | | 147 11 | | 306 19 | 23 |
| 30 | 203 20 | · · | 264 16 | 157 19 | · · | 265 10 | · · | 149 42 | · · | 308 43 | · 21 |
| 40 | 205 50 | | 266 46 | 159 49 | | 267 40 | | 152 12 | | 311 07 | 20 |
| 50 | 208 20 | | 269 17 | 162 19 | | 270 10 | | 154 42 | | 313 32 | 19 |
| 2 00 | 210 50 | N20 46 | 271 47 | 164 49 | N25 00 | 272 40 | S 2 17 | 157 13 | N21 57 | 315 56 | S16 18 |
| 10 | 213 20 | | 274 18 | 167 19 | | 275 10 | | 159 43 | | 318 20 | 17 |
| 20 | 215 50 | | 276 48 | 169 49 | | 277 41 | | 162 13 | | 320 45 | 15 |
| 30 | 218 20 | · · | 279 18 | 172 19 | · · | 280 11 | · · | 164 44 | · · | 323 09 | · 14 |
| 40 | 220 50 | | 281 49 | 174 49 | | 282 41 | | 167 14 | | 325 33 | 13 |
| 50 | 223 20 | | 284 19 | 177 19 | | 285 11 | | 169 44 | | 327 58 | 12 |
| 3 00 | 225 50 | N20 46 | 286 50 | 179 49 | N25 00 | 287 41 | S 2 16 | 172 15 | N21 57 | 330 22 | S16 11 |
| 10 | 228 20 | | 289 20 | 182 18 | | 290 11 | | 174 45 | | 332 46 | 09 |
| 20 | 230 50 | | 291 51 | 184 48 | | 292 41 | | 177 15 | | 335 11 | 08 |
| 30 | 233 20 | · · | 294 21 | 187 18 | · · | 295 11 | · · | 179 46 | · · | 337 35 | · 07 |
| 40 | 235 50 | | 296 51 | 189 48 | | 297 42 | | 182 16 | | 339 59 | 06 |
| 50 | 238 20 | | 299 22 | 192 18 | | 300 12 | | 184 46 | | 342 24 | 04 |
| 4 00 | 240 50 | N20 47 | 301 52 | 194 48 | N25 00 | 302 42 | S 2 15 | 187 17 | N21 57 | 344 48 | S16 03 |
| 10 | 243 20 | | 304 23 | 197 18 | | 305 12 | | 189 47 | | 347 12 | 02 |
| 20 | 245 50 | | 306 53 | 199 48 | | 307 42 | | 192 17 | | 349 37 | 01 |
| 30 | 248 20 | · · | 309 23 | 202 18 | · · | 310 12 | · · | 194 48 | · · | 352 01 | ·16 00 |
| 40 | 250 50 | | 311 54 | 204 48 | | 312 42 | | 197 18 | | 354 25 | 15 58 |
| 50 | 253 20 | | 314 24 | 207 18 | | 315 12 | | 199 48 | | 356 50 | 57 |
| 5 00 | 255 50 | N20 47 | 316 55 | 209 47 | N24 59 | 317 43 | S 2 15 | 202 19 | N21 57 | 359 14 | S15 56 |
| 10 | 258 20 | | 319 25 | 212 17 | | 320 13 | | 204 49 | | 1 38 | 55 |
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| 30 | 263 20 | · · | 324 26 | 217 17 | · · | 325 13 | · · | 209 50 | · · | 6 27 | · 52 |
| 40 | 265 50 | | 326 56 | 219 47 | | 327 43 | | 212 20 | | 8 52 | 51 |
| 50 | 268 20 | | 329 27 | 222 17 | | 330 13 | | 214 50 | | 11 16 | 50 |
| 6 00 | 270 50 | N20 48 | 331 57 | 224 47 | N24 59 | 332 43 | S 2 14 | 217 21 | N21 57 | 13 40 | S15 48 |
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| 30 | 278 20 | · · | 339 28 | 232 17 | · · | 340 14 | · · | 224 52 | · · | 20 53 | · 45 |
| 40 | 280 50 | | 341 59 | 234 46 | | 342 44 | | 227 22 | | 23 18 | 43 |
| 50 | 283 20 | | 344 29 | 237 16 | | 345 14 | | 229 52 | | 25 42 | 42 |
| 7 00 | 285 50 | N20 48 | 347 00 | 239 46 | N24 59 | 347 44 | S 2 13 | 232 23 | N21 57 | 28 07 | S15 41 |
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| 40 | 295 50 | | 357 01 | 249 46 | | 357 45 | | 242 24 | | 37 44 | 36 |
| 50 | 298 20 | | 359 32 | 252 16 | | 0 15 | | 244 54 | | 40 08 | 34 |
| 8 00 | 300 50 | N20 48 | 2 02 | 254 46 | N24 58 | 2 45 | S 2 12 | 247 25 | N21 57 | 42 33 | S15 33 |
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| 20 | 305 50 | | 7 03 | 259 46 | | 7 45 | | 252 25 | | 47 22 | 30 |
| 30 | 308 20 | · · | 9 33 | 262 15 | · · | 10 15 | · · | 254 56 | · · | 49 46 | · 29 |
| 40 | 310 50 | | 12 04 | 264 45 | | 12 45 | | 257 26 | | 52 10 | 28 |
| 50 | 313 20 | | 14 34 | 267 15 | | 15 15 | | 259 56 | | 54 35 | 27 |
| 9 00 | 315 50 | N20 49 | 17 05 | 269 45 | N24 58 | 17 46 | S 2 12 | 262 27 | N21 57 | 56 59 | S15 25 |
| 10 | 318 20 | | 19 35 | 272 15 | | 20 16 | | 264 57 | | 59 24 | 24 |
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| 30 | 323 20 | · · | 24 36 | 277 15 | · · | 25 16 | · · | 269 58 | · · | 64 12 | · 21 |
| 40 | 325 50 | | 27 06 | 279 45 | | 27 46 | | 272 28 | | 66 37 | 20 |
| 50 | 328 20 | | 29 37 | 282 15 | | 30 16 | | 274 58 | | 69 01 | 19 |
| 10 00 | 330 50 | N20 49 | 32 07 | 284 45 | N24 58 | 32 46 | S 2 11 | 277 29 | N21 57 | 71 26 | S15 17 |
| 10 | 333 20 | | 34 37 | 287 14 | | 35 16 | | 279 59 | | 73 50 | 16 |
| 20 | 335 49 | | 37 08 | 289 44 | | 37 47 | | 282 29 | | 76 14 | 15 |
| 30 | 338 19 | · · | 39 38 | 292 14 | · · | 40 17 | · · | 285 00 | · · | 78 39 | · 13 |
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| 50 | 343 19 | | 44 39 | 297 14 | | 45 17 | | 290 00 | | 83 28 | 11 |
| 11 00 | 345 49 | N20 50 | 47 09 | 299 44 | N24 57 | 47 47 | S 2 10 | 292 31 | N21 57 | 85 52 | S15 09 |
| 10 | 348 19 | | 49 40 | 302 14 | | 50 17 | | 295 01 | | 88 17 | 08 |
| 20 | 350 49 | | 52 10 | 304 44 | | 52 47 | | 297 31 | | 90 41 | 07 |
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☾ Par.

| Alt. ° | + Corr. ′ |
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| 25 | 53 |
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| 68 | 21 |
| 69 | 20 |
| 70 | 19 |
| 71 | 18 |
| 72 | 17 |
| 73 | 16 |
| 74 | 15 |
| 75 | 14 |
| 76 | 13 |
| 77 | 12 |
| 78 | 11 |
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SD, ☉ 16

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| m Int. | ′ Corr. |
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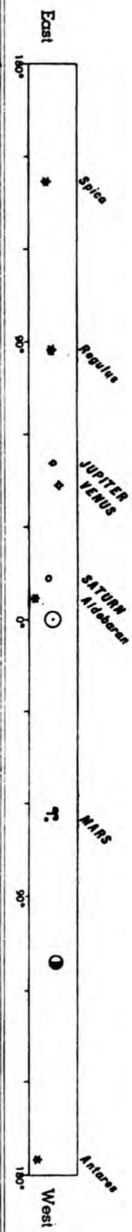




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# GREENWICH P. M. 1943 MAY 25 (TUESDAY)

| GCT | ☉ SUN GHA | Dec. | ♈ GHA | VENUS −3.6 GHA | Dec. | MARS 0.9 GHA | Dec. | JUPITER −1.5 GHA | Dec. | ◑ MOON GHA | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 12 00 | 0 49 | N20 50 | 62 12 | 314 43 | N24 57 | 62 48 | S 2 10 | 307 33 | N21 57 | 100 19 | S15 01 |
| 10 | 3 19 | | 64 42 | 317 13 | | 65 18 | | 310 03 | | 102 43 | 15 00 |
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| 30 | 8 19 · | · | 69 43 | 322 13 · | · | 70 18 · | · | 315 04 · | · | 107 32 · | 57 |
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| 13 00 | 15 49 | N20 51 | 77 14 | 329 43 | N24 57 | 77 49 | S 2 09 | 322 35 | N21 56 | 114 45 | S14 53 |
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| 20 | 20 49 | | 82 15 | 334 43 | | 82 49 | | 327 35 | | 119 34 | 50 |
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| 20 | 110 49 | | 172 30 | 64 39 | | 172 53 | | 57 47 | | 206 16 | 13 59 |
| 30 | 113 19 · | · | 175 00 | 67 09 · | · | 175 23 · | · | 60 18 · | · | 208 40 · | 58 |
| 40 | 115 49 | | 177 31 | 69 39 | | 177 54 | | 62 48 | | 211 05 | 57 |
| 50 | 118 19 | | 180 01 | 72 09 | | 180 24 | | 65 18 | | 213 29 | 55 |
| 20 00 | 120 49 | N20 54 | 182 32 | 74 39 | N24 55 | 182 54 | S 2 04 | 67 48 | N21 56 | 215 54 | S13 54 |
| 10 | 123 19 | | 185 02 | 77 09 | | 185 24 | | 70 19 | | 218 18 | 52 |
| 20 | 125 49 | | 187 32 | 79 39 | | 187 54 | | 72 49 | | 220 43 | 51 |
| 30 | 128 19 · | · | 190 03 | 82 08 · | · | 190 24 · | · | 75 19 · | · | 223 07 · | 49 |
| 40 | 130 49 | | 192 33 | 84 38 | | 192 54 | | 77 50 | | 225 32 | 48 |
| 50 | 133 19 | | 195 04 | 87 08 | | 195 24 | | 80 20 | | 227 56 | 46 |
| 21 00 | 135 49 | N20 54 | 197 34 | 89 38 | N24 54 | 197 54 | S 2 03 | 82 50 | N21 56 | 230 21 | S13 45 |
| 10 | 138 19 | | 200 04 | 92 08 | | 200 25 | | 85 21 | | 232 45 | 43 |
| 20 | 140 49 | | 202 35 | 94 38 | | 202 55 | | 87 51 | | 235 10 | 42 |
| 30 | 143 19 · | · | 205 05 | 97 08 · | · | 205 25 · | · | 90 21 · | · | 237 35 · | 40 |
| 40 | 145 49 | | 207 36 | 99 38 | | 207 55 | | 92 52 | | 239 59 | 39 |
| 50 | 148 19 | | 210 06 | 102 08 | | 210 25 | | 95 22 | | 242 24 | 37 |
| 22 00 | 150 49 | N20 55 | 212 37 | 104 38 | N24 54 | 212 55 | S 2 02 | 97 52 | N21 56 | 244 48 | S13 36 |
| 10 | 153 19 | | 215 07 | 107 08 | | 215 25 | | 100 23 | | 247 13 | 34 |
| 20 | 155 49 | | 217 37 | 109 37 | | 217 55 | | 102 53 | | 249 37 | 33 |
| 30 | 158 19 · | · | 220 08 | 112 07 · | · | 220 26 · | · | 105 23 · | · | 252 02 · | 31 |
| 40 | 160 49 | | 222 38 | 114 37 | | 222 56 | | 107 54 | | 254 26 | 30 |
| 50 | 163 19 | | 225 09 | 117 07 | | 225 26 | | 110 24 | | 256 51 | 28 |
| 23 00 | 165 49 | N20 55 | 227 39 | 119 37 | N24 54 | 227 56 | S 2 02 | 112 54 | N21 56 | 259 16 | S13 27 |
| 10 | 168 19 | | 230 09 | 122 07 | | 230 26 | | 115 25 | | 261 40 | 25 |
| 20 | 170 49 | | 232 40 | 124 37 | | 232 56 | | 117 55 | | 264 05 | 24 |
| 30 | 173 19 · | · | 235 10 | 127 07 · | · | 235 26 · | · | 120 25 · | · | 266 29 · | 22 |
| 40 | 175 49 | | 237 41 | 129 37 | | 237 56 | | 122 56 | | 268 54 | 21 |
| 50 | 178 19 | | 240 11 | 132 07 | | 240 27 | | 125 26 | | 271 18 | 19 |
| 24 00 | 180 49 | N20 56 | 242 41 | 134 36 | N24 53 | 242 57 | S 2 01 | 127 56 | N21 56 | 273 43 | S13 18 |

| Lat. | Sun-rise | Twil. | Moon-rise | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | □ | □ | 2 33 | * |
| 68 | 0 44 | //// | 2 04 | 07 |
| 66 | 1 45 | //// | 1 42 | 14 |
| 64 | 2 19 | //// | 25 | 19 |
| 62 | 2 44 | 94 | 1 10 | 23 |
| 60 | 3 03 | 74 | 0 58 | 27 |
| 58 | 19 | 63 | 48 | 29 |
| 56 | 32 | 55 | 38 | 32 |
| 54 | 44 | 50 | 30 | 34 |
| 52 | 3 54 | 45 | 23 | 35 |
| 50 | 4 03 | 42 | 16 | 37 |
| 45 | 22 | 36 | 0 02 | 40 |
| 40 | 38 | 32 | 24 32 | 38 |
| 35 | 4 50 | 29 | 25 | 40 |
| 30 | 5 02 | 27 | 18 | 42 |
| 20 | 21 | 24 | 24 06 | 46 |
| 10 | 38 | 23 | 23 55 | 50 |
| 0 | 5 53 | 22 | 45 | 53 |
| 10 | 6 09 | 23 | 35 | 56 |
| 20 | 25 | 24 | 24 | 60 |
| 30 | 44 | 25 | 13 | 63 |
| 35 | 6 54 | 27 | 23 05 | 66 |
| 40 | 7 06 | 30 | 22 57 | 68 |
| 45 | 21 | 32 | 48 | 71 |
| 50 | 38 | 36 | 37 | 74 |
| 52 | 47 | 38 | 31 | 77 |
| 54 | 7 56 | 40 | 26 | 78 |
| 56 | 8 06 | 43 | 19 | 80 |
| 58 | 18 | 46 | 12 | 83 |
| 60 | 8 32 | 51 | 22 03 | 86 |
| S | | | | |

| Lat. | Sun-set | Twil. | Moon-set | Diff. |
|---|---|---|---|---|
| N ° | h m | m | h m | m |
| 70 | □ | □ | 7 46 | 118 |
| 68 | 23 21 | //// | 8 14 | 107 |
| 66 | 22 12 | //// | 35 | 100 |
| 64 | 21 37 | //// | 8 52 | 94 |
| 62 | 21 12 | 97 | 9 06 | 89 |
| 60 | 20 52 | 74 | 18 | 86 |
| 58 | 36 | 62 | 28 | 83 |
| 56 | 22 | 55 | 36 | 81 |
| 54 | 10 | 50 | 44 | 78 |
| 52 | 20 00 | 45 | 51 | 76 |
| 50 | 19 51 | 42 | 9 58 | 74 |
| 45 | 32 | 36 | 10 11 | 71 |
| 40 | 16 | 32 | 21 | 69 |
| 35 | 19 03 | 29 | 31 | 66 |
| 30 | 18 52 | 27 | 39 | 64 |
| 20 | 32 | 24 | 10 53 | 60 |
| 10 | 16 | 23 | 11 05 | 57 |
| 0 | 18 00 | 22 | 17 | 54 |
| 10 | 17 45 | 23 | 28 | 51 |
| 20 | 29 | 24 | 40 | 48 |
| 30 | 11 | 26 | 11 54 | 44 |
| 35 | 17 00 | 28 | 12 01 | 43 |
| 40 | 16 48 | 30 | 10 | 40 |
| 45 | 33 | 32 | 21 | 37 |
| 50 | 16 | 37 | 33 | 34 |
| 52 | 16 07 | 39 | 39 | 32 |
| 54 | 15 58 | 41 | 45 | 31 |
| 56 | 48 | 44 | 12 53 | 28 |
| 58 | 36 | 48 | 13 00 | 26 |
| 60 | 15 22 | 52 | 13 09 | 24 |
| S | | | | |



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## GREENWICH A. M. 1943 MAY 30 (SUNDAY)

| GCT h m | ☉ SUN GHA ° ' | Dec. ° ' | ♈ GHA ° ' | VENUS −3.6 GHA ° ' | Dec. ° ' | MARS 0.9 GHA ° ' | Dec. ° ' | JUPITER −1.5 GHA ° ' | Dec. ° ' | ☾ MOON GHA ° ' | Dec. ° ' |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 00 | 180 42 | N21 36 | 246 38 | 133 45 | N24 17 | 244 09 | S 0 51 | 131 07 | N21 48 | 225 33 | N 4 04 |
| 10 | 183 12 | | 249 08 | 136 15 | | 246 39 | | 133 37 | | 227 58 | 06 |
| 20 | 185 42 | | 251 39 | 138 45 | | 249 10 | | 136 07 | | 230 23 | 07 |
| 30 | 188 12 | · · | 254 09 | 141 15 | · · | 251 40 | · · | 138 38 | · · | 232 48 | · 09 |
| 40 | 190 42 | | 256 40 | 143 44 | | 254 10 | | 141 08 | | 235 13 | 11 |
| 50 | 193 12 | | 259 10 | 146 14 | | 256 40 | | 143 38 | | 237 39 | 13 |
| 1 00 | 195 42 | N21 36 | 261 40 | 148 44 | N24 16 | 259 10 | S 0 51 | 146 08 | N21 48 | 240 04 | N 4 15 |
| 10 | 198 12 | | 264 11 | 151 14 | | 261 40 | | 148 39 | | 242 29 | 17 |
| 20 | 200 42 | | 266 41 | 153 44 | | 264 10 | | 151 09 | | 244 54 | 18 |
| 30 | 203 12 | · · | 269 12 | 156 14 | · · | 266 40 | · · | 153 39 | · · | 247 20 | · 20 |
| 40 | 205 42 | | 271 42 | 158 44 | | 269 11 | | 156 10 | | 249 45 | 22 |
| 50 | 208 12 | | 274 13 | 161 14 | | 271 41 | | 158 40 | | 252 10 | 24 |
| 2 00 | 210 42 | N21 37 | 276 43 | 163 44 | N24 16 | 274 11 | S 0 50 | 161 10 | N21 48 | 254 35 | N 4 26 |
| 10 | 213 12 | | 279 13 | 166 14 | | 276 41 | | 163 41 | | 257 00 | 28 |
| 20 | 215 42 | | 281 44 | 168 44 | | 279 11 | | 166 11 | | 259 26 | 29 |
| 30 | 218 12 | · · | 284 14 | 171 14 | · · | 281 41 | · · | 168 41 | · · | 261 51 | · 31 |
| 40 | 220 42 | | 286 45 | 173 43 | | 284 11 | | 171 12 | | 264 16 | 33 |
| 50 | 223 12 | | 289 15 | 176 13 | | 286 41 | | 173 42 | | 266 41 | 35 |
| 3 00 | 225 42 | N21 37 | 291 45 | 178 43 | N24 15 | 289 12 | S 0 49 | 176 12 | N21 48 | 269 07 | N 4 37 |
| 10 | 228 12 | | 294 16 | 181 13 | | 291 42 | | 178 43 | | 271 32 | 39 |
| 20 | 230 42 | | 296 46 | 183 43 | | 294 12 | | 181 13 | | 273 57 | 40 |
| 30 | 233 12 | · · | 299 17 | 186 13 | · · | 296 42 | · · | 183 43 | · · | 276 22 | · 42 |
| 40 | 235 42 | | 301 47 | 188 43 | | 299 12 | | 186 14 | | 278 47 | 44 |
| 50 | 238 12 | | 304 17 | 191 13 | | 301 42 | | 188 44 | | 281 13 | 46 |
| 4 00 | 240 42 | N21 38 | 306 48 | 193 43 | N24 15 | 304 12 | S 0 48 | 191 14 | N21 48 | 283 38 | N 4 48 |
| 10 | 243 12 | | 309 18 | 196 13 | | 306 42 | | 193 45 | | 286 03 | 49 |
| 20 | 245 42 | | 311 49 | 198 43 | | 309 13 | | 196 15 | | 288 28 | 51 |
| 30 | 248 12 | · · | 314 19 | 201 12 | · · | 311 43 | · · | 198 45 | · · | 290 54 | · 53 |
| 40 | 250 42 | | 316 50 | 203 42 | | 314 13 | | 201 16 | | 293 19 | 55 |
| 50 | 253 12 | | 319 20 | 206 12 | | 316 43 | | 203 46 | | 295 44 | 57 |
| 5 00 | 255 42 | N21 38 | 321 50 | 208 42 | N24 14 | 319 13 | S 0 48 | 206 16 | N21 48 | 298 09 | N 4 58 |
| 10 | 258 12 | | 324 21 | 211 12 | | 321 43 | | 208 47 | | 300 34 | 5 00 |
| 20 | 260 42 | | 326 51 | 213 42 | | 324 13 | | 211 17 | | 303 00 | 02 |
| 30 | 263 12 | · · | 329 22 | 216 12 | · · | 326 43 | · · | 213 47 | · · | 305 25 | · 04 |
| 40 | 265 42 | | 331 52 | 218 42 | | 329 14 | | 216 18 | | 307 50 | 06 |
| 50 | 268 12 | | 334 22 | 221 12 | | 331 44 | | 218 48 | | 310 15 | 07 |
| 6 00 | 270 41 | N21 38 | 336 53 | 223 42 | N24 14 | 334 14 | S 0 47 | 221 18 | N21 48 | 312 41 | N 5 09 |
| 10 | 273 11 | | 339 23 | 226 12 | | 336 44 | | 223 49 | | 315 06 | 11 |
| 20 | 275 41 | | 341 54 | 228 42 | | 339 14 | | 226 19 | | 317 31 | 13 |
| 30 | 278 11 | · · | 344 24 | 231 11 | · · | 341 44 | · · | 228 49 | · · | 319 56 | · 15 |
| 40 | 280 41 | | 346 54 | 233 41 | | 344 14 | | 231 20 | | 322 22 | 17 |
| 50 | 283 11 | | 349 25 | 236 11 | | 346 45 | | 233 50 | | 324 47 | 18 |
| 7 00 | 285 41 | N21 39 | 351 55 | 238 41 | N24 14 | 349 15 | S 0 46 | 236 20 | N21 48 | 327 12 | N 5 20 |
| 10 | 288 11 | | 354 26 | 241 11 | | 351 45 | | 238 51 | | 329 37 | 22 |
| 20 | 290 41 | | 356 56 | 243 41 | | 354 15 | | 241 21 | | 332 02 | 24 |
| 30 | 293 11 | · · | 359 26 | 246 11 | · · | 356 45 | · · | 243 51 | · · | 334 28 | · 25 |
| 40 | 295 41 | | 1 57 | 248 41 | | 359 15 | | 246 22 | | 336 53 | 27 |
| 50 | 298 11 | | 4 27 | 251 11 | | 1 45 | | 248 52 | | 339 18 | 29 |
| 8 00 | 300 41 | N21 39 | 6 58 | 253 41 | N24 13 | 4 15 | S 0 46 | 251 22 | N21 48 | 341 43 | N 5 31 |
| 10 | 303 11 | | 9 28 | 256 11 | | 6 46 | | 253 53 | | 344 09 | 33 |
| 20 | 305 41 | | 11 59 | 258 41 | | 9 16 | | 256 23 | | 346 34 | 34 |
| 30 | 308 11 | · · | 14 29 | 261 10 | · · | 11 46 | · · | 258 53 | · · | 348 59 | · 36 |
| 40 | 310 41 | | 16 59 | 263 40 | | 14 16 | | 261 24 | | 351 24 | 38 |
| 50 | 313 11 | | 19 30 | 266 10 | | 16 46 | | 263 54 | | 353 49 | 40 |
| 9 00 | 315 41 | N21 40 | 22 00 | 268 40 | N24 13 | 19 16 | S 0 45 | 266 24 | N21 48 | 356 15 | N 5 42 |
| 10 | 318 11 | | 24 31 | 271 10 | | 21 46 | | 268 55 | | 358 40 | 43 |
| 20 | 320 41 | | 27 01 | 273 40 | | 24 16 | | 271 25 | | 1 05 | 45 |
| 30 | 323 11 | · · | 29 31 | 276 10 | · · | 26 47 | · · | 273 55 | · · | 3 30 | · 47 |
| 40 | 325 41 | | 32 02 | 278 40 | | 29 17 | | 276 26 | | 5 56 | 49 |
| 50 | 328 11 | | 34 32 | 281 10 | | 31 47 | | 278 56 | | 8 21 | 51 |
| 10 00 | 330 41 | N21 40 | 37 03 | 283 40 | N24 12 | 34 17 | S 0 44 | 281 26 | N21 48 | 10 46 | N 5 52 |
| 10 | 333 11 | | 39 33 | 286 10 | | 36 47 | | 283 56 | | 13 11 | 54 |
| 20 | 335 41 | | 42 03 | 288 40 | | 39 17 | | 286 27 | | 15 37 | 56 |
| 30 | 338 11 | · · | 44 34 | 291 09 | · · | 41 47 | · · | 288 57 | · · | 18 02 | 58 |
| 40 | 340 41 | | 47 04 | 293 39 | | 44 17 | | 291 27 | | 20 27 | 5 59 |
| 50 | 343 11 | | 49 35 | 296 09 | | 46 48 | | 293 58 | | 22 52 | 6 01 |
| 11 00 | 345 41 | N21 40 | 52 05 | 298 39 | N24 12 | 49 18 | S 0 43 | 296 28 | N21 48 | 25 17 | N 6 03 |
| 10 | 348 11 | | 54 36 | 301 09 | | 51 48 | | 298 58 | | 27 43 | 05 |
| 20 | 350 41 | | 57 06 | 303 39 | | 54 18 | | 301 29 | | 30 08 | 07 |
| 30 | 353 11 | · · | 59 36 | 306 09 | · · | 56 48 | · · | 303 59 | · · | 32 33 | · 08 |
| 40 | 355 41 | | 62 07 | 308 39 | | 59 18 | | 306 29 | | 34 58 | 10 |
| 50 | 358 11 | | 64 37 | 311 09 | | 61 48 | | 309 00 | | 37 24 | 12 |
| 12 00 | 0 41 | N21 41 | 67 08 | 313 39 | N24 11 | 64 18 | S 0 43 | 311 30 | N21 47 | 39 49 | N 6 14 |

☾ Par.

| Alt. ° | Corr. + ' |
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| 6 | 56 |
| 12 | 55 |
| 16 | 54 |
| 19 | 53 |
| 22 | 52 |
| 25 | 51 |
| 27 | 50 |
| 29 | 49 |
| 31 | 48 |
| 33 | 47 |
| 35 | 46 |
| 36 | 45 |
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| 64 | 24 |
| 65 | 23 |
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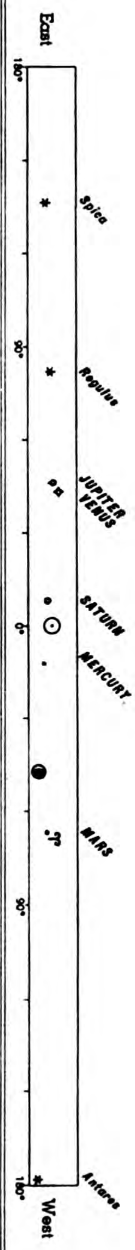
| 68 | 20 |
| 69 | 19 |
| 71 | 18 |
| 72 | 17 |
| 73 | 16 |
| 74 | 15 |
| 75 | 14 |
| 76 | 13 |
| 77 | 12 |
| 78 | 11 |
| 79 | 10 |
| 80 | |

SD ☉ ' 16

SD ☾ ' 15

Corr. HA ☾

| Int. m | Corr. ' |
|---|---|
| 0 | 0 |
| 10 | |



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## GREENWICH P. M. 1943 MAY 30 (SUNDAY)

| GCT h m | ☉ SUN GHA | SUN Dec. | ♈ GHA | VENUS − 3.6 GHA | VENUS Dec. | MARS 0.9 GHA | MARS Dec. | JUPITER − 1.5 GHA | JUPITER Dec. | ● MOON GHA | MOON Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 00 | 0 41 | N21 41 | 67 08 | 313 39 | N24 11 | 64 18 | S 0 43 | 311 30 | N21 47 | 39 49 | N 6 14 |
| 10 | 3 11 | | 69 38 | 316 09 | | 66 49 | | 314 00 | | 42 14 | 15 |
| 20 | 5 41 | | 72 08 | 318 39 | | 69 19 | | 316 31 | | 44 39 | 17 |
| 30 | 8 11 | · · | 74 39 | 321 09 | · · | 71 49 | · · | 319 01 | · · | 47 05 | · 19 |
| 40 | 10 41 | | 77 09 | 323 38 | | 74 19 | | 321 31 | | 49 30 | 21 |
| 50 | 13 11 | | 79 40 | 326 08 | | 76 49 | | 324 02 | | 51 55 | 22 |
| 13 00 | 15 41 | N21 41 | 82 10 | 328 38 | N24 11 | 79 19 | S 0 42 | 326 32 | N21 47 | 54 20 | N 6 24 |
| 10 | 18 11 | | 84 40 | 331 08 | | 81 49 | | 329 02 | | 56 45 | 26 |
| 20 | 20 41 | | 87 11 | 333 38 | | 84 19 | | 331 33 | | 59 11 | 28 |
| 30 | 23 11 | · · | 89 41 | 336 08 | · · | 86 50 | · · | 334 03 | · · | 61 36 | · 29 |
| 40 | 25 41 | | 92 12 | 338 38 | | 89 20 | | 336 33 | | 64 01 | 31 |
| 50 | 28 11 | | 94 42 | 341 08 | | 91 50 | | 339 04 | | 66 26 | 33 |
| 14 00 | 30 41 | N21 41 | 97 13 | 343 38 | N24 10 | 94 20 | S 0 41 | 341 34 | N21 47 | 68 52 | N 6 35 |
| 10 | 33 11 | | 99 43 | 346 08 | | 96 50 | | 344 04 | | 71 17 | 36 |
| 20 | 35 41 | | 102 13 | 348 38 | | 99 20 | | 346 35 | | 73 42 | 38 |
| 30 | 38 11 | · · | 104 44 | 351 08 | · · | 101 50 | · · | 349 05 | · · | 76 07 | · 40 |
| 40 | 40 41 | | 107 14 | 353 37 | | 104 21 | | 351 35 | | 78 32 | 42 |
| 50 | 43 11 | | 109 45 | 356 07 | | 106 51 | | 354 06 | | 80 58 | 44 |
| 15 00 | 45 41 | N21 42 | 112 15 | 358 37 | N24 10 | 109 21 | S 0 40 | 356 36 | N21 47 | 83 23 | N 6 45 |
| 10 | 48 11 | | 114 45 | 1 07 | | 111 51 | | 359 06 | | 85 48 | 47 |
| 20 | 50 41 | | 117 16 | 3 37 | | 114 21 | | 1 37 | | 88 13 | 49 |
| 30 | 53 11 | · · | 119 46 | 6 07 | · · | 116 51 | · · | 4 07 | · · | 90 39 | · 51 |
| 40 | 55 41 | | 122 17 | 8 37 | | 119 21 | | 6 37 | | 93 04 | 52 |
| 50 | 58 11 | | 124 47 | 11 07 | | 121 51 | | 9 08 | | 95 29 | 54 |
| 16 00 | 60 41 | N21 42 | 127 17 | 13 37 | N24 10 | 124 22 | S 0 40 | 11 38 | N21 47 | 97 54 | N 6 56 |
| 10 | 63 11 | | 129 48 | 16 07 | | 126 52 | | 14 08 | | 100 20 | 57 |
| 20 | 65 41 | | 132 18 | 18 37 | | 129 22 | | 16 39 | | 102 45 | 6 59 |
| 30 | 68 11 | · · | 134 49 | 21 07 | · · | 131 52 | · · | 19 09 | · · | 105 10 | · 7 01 |
| 40 | 70 41 | | 137 19 | 23 36 | | 134 22 | | 21 39 | | 107 35 | 03 |
| 50 | 73 11 | | 139 49 | 26 06 | | 136 52 | | 24 10 | | 110 00 | 04 |
| 17 00 | 75 41 | N21 43 | 142 20 | 28 36 | N24 09 | 139 22 | S 0 39 | 26 40 | N21 47 | 112 26 | N 7 06 |
| 10 | 78 11 | | 144 50 | 31 06 | | 141 52 | | 29 10 | | 114 51 | 08 |
| 20 | 80 40 | | 147 21 | 33 36 | | 144 23 | | 31 41 | | 117 16 | 10 |
| 30 | 83 10 | · · | 149 51 | 36 06 | · · | 146 53 | · · | 34 11 | · · | 119 41 | · 11 |
| 40 | 85 40 | | 152 22 | 38 36 | | 149 23 | | 36 41 | | 122 07 | 13 |
| 50 | 88 10 | | 154 52 | 41 06 | | 151 53 | | 39 12 | | 124 32 | 15 |
| 18 00 | 90 40 | N21 43 | 157 22 | 43 36 | N24 09 | 154 23 | S 0 38 | 41 42 | N21 47 | 126 57 | N 7 17 |
| 10 | 93 10 | | 159 53 | 46 06 | | 156 53 | | 44 12 | | 129 22 | 18 |
| 20 | 95 40 | | 162 23 | 48 36 | | 159 23 | | 46 43 | | 131 47 | 20 |
| 30 | 98 10 | · · | 164 54 | 51 06 | · · | 161 53 | · · | 49 13 | · · | 134 13 | · 22 |
| 40 | 100 40 | | 167 24 | 53 35 | | 164 24 | | 51 43 | | 136 38 | 23 |
| 50 | 103 10 | | 169 54 | 56 05 | | 166 54 | | 54 14 | | 139 03 | 25 |
| 19 00 | 105 40 | N21 43 | 172 25 | 58 35 | N24 08 | 169 24 | S 0 38 | 56 44 | N21 47 | 141 28 | N 7 27 |
| 10 | 108 10 | | 174 55 | 61 05 | | 171 54 | | 59 14 | | 143 54 | 29 |
| 20 | 110 40 | | 177 26 | 63 35 | | 174 24 | | 61 44 | | 146 19 | 30 |
| 30 | 113 10 | · · | 179 56 | 66 05 | · · | 176 54 | · · | 64 15 | · · | 148 44 | · 32 |
| 40 | 115 40 | | 182 26 | 68 35 | | 179 24 | | 66 45 | | 151 09 | 34 |
| 50 | 118 10 | | 184 57 | 71 05 | | 181 54 | | 69 15 | | 153 34 | 35 |
| 20 00 | 120 40 | N21 44 | 187 27 | 73 35 | N24 08 | 184 25 | S 0 37 | 71 46 | N21 47 | 156 00 | N 7 37 |
| 10 | 123 10 | | 189 58 | 76 05 | | 186 55 | | 74 16 | | 158 25 | 39 |
| 20 | 125 40 | | 192 28 | 78 35 | | 189 25 | | 76 46 | | 160 50 | 41 |
| 30 | 128 10 | · · | 194 59 | 81 05 | · · | 191 55 | · · | 79 17 | · · | 163 15 | · 42 |
| 40 | 130 40 | | 197 29 | 83 35 | | 194 25 | | 81 47 | | 165 41 | 44 |
| 50 | 133 10 | | 199 59 | 86 04 | | 196 55 | | 84 17 | | 168 06 | 46 |
| 21 00 | 135 40 | N21 44 | 202 30 | 88 34 | N24 07 | 199 25 | S 0 36 | 86 48 | N21 47 | 170 31 | N 7 48 |
| 10 | 138 10 | | 205 00 | 91 04 | | 201 55 | | 89 18 | | 172 56 | 49 |
| 20 | 140 40 | | 207 31 | 93 34 | | 204 26 | | 91 48 | | 175 22 | 51 |
| 30 | 143 10 | · · | 210 01 | 96 04 | · · | 206 56 | · · | 94 19 | · · | 177 47 | · 53 |
| 40 | 145 40 | | 212 31 | 98 34 | | 209 26 | | 96 49 | | 180 12 | 54 |
| 50 | 148 10 | | 215 02 | 101 04 | | 211 56 | | 99 19 | | 182 37 | 56 |
| 22 00 | 150 40 | N21 45 | 217 32 | 103 34 | N24 07 | 214 26 | S 0 35 | 101 50 | N21 47 | 185 02 | N 7 58 |
| 10 | 153 10 | | 220 03 | 106 04 | | 216 56 | | 104 20 | | 187 28 | 7 59 |
| 20 | 155 40 | | 222 33 | 108 34 | | 219 26 | | 106 50 | | 189 53 | 8 01 |
| 30 | 158 10 | · · | 225 03 | 111 04 | · · | 221 57 | · · | 109 21 | · · | 192 18 | · 03 |
| 40 | 160 40 | | 227 34 | 113 34 | | 224 27 | | 111 51 | | 194 43 | 05 |
| 50 | 163 10 | | 230 04 | 116 03 | | 226 57 | | 114 21 | | 197 09 | 06 |
| 23 00 | 165 40 | N21 45 | 232 35 | 118 33 | N24 06 | 229 27 | S 0 35 | 116 52 | N21 47 | 199 34 | N 8 08 |
| 10 | 168 10 | | 235 05 | 121 03 | | 231 57 | | 119 22 | | 201 59 | 10 |
| 20 | 170 40 | | 237 36 | 123 33 | | 234 27 | | 121 52 | | 204 24 | 11 |
| 30 | 173 10 | · · | 240 06 | 126 03 | · · | 236 57 | · · | 124 23 | · · | 206 49 | · 13 |
| 40 | 175 40 | | 242 36 | 128 33 | | 239 27 | | 126 53 | | 209 15 | 15 |
| 50 | 178 10 | | 245 07 | 131 03 | | 241 58 | | 129 23 | | 211 40 | 16 |
| 24 00 | 180 40 | N21 45 | 247 37 | 133 33 | N24 06 | 244 28 | S 0 34 | 131 54 | N21 47 | 214 05 | N 8 18 |

| Lat. ° | Sunrise h m | Twil. m | Moonrise h m | Diff. m |
|---|---|---|---|---|
| N | | | | |
| 70 | □ | □ | 2 14 | * |
| 68 | □ | □ | 19 | 01 |
| 66 | 1 25 | //// | 23 | 06 |
| 64 | 2 05 | //// | 26 | 10 |
| 62 | 33 | 115 | 30 | 12 |
| 60 | 2 54 | 80 | 32 | 16 |
| 58 | 3 11 | 65 | 35 | 18 |
| 56 | 25 | 56 | 37 | 20 |
| 54 | 38 | 51 | 39 | 22 |
| 52 | 49 | 46 | 40 | 25 |
| 50 | 3 58 | 42 | 42 | 26 |
| 45 | 4 18 | 37 | 46 | 29 |
| 40 | 35 | 32 | 48 | 32 |
| 35 | 4 48 | 29 | 51 | 35 |
| 30 | 5 00 | 27 | 53 | 37 |
| 20 | 20 | 24 | 2 57 | 41 |
| 10 | 38 | 23 | 3 01 | 44 |
| 0 | 5 54 | 22 | 04 | 48 |
| 10 | 6 09 | 23 | 08 | 50 |
| 20 | 26 | 24 | 11 | 54 |
| 30 | 46 | 26 | 15 | 58 |
| 35 | 6 57 | 28 | 18 | 60 |
| 40 | 7 10 | 30 | 21 | 62 |
| 45 | 25 | 33 | 24 | 66 |
| 50 | 43 | 37 | 28 | 69 |
| 52 | 7 52 | 38 | 29 | 72 |
| 54 | 8 02 | 41 | 31 | 73 |
| 56 | 13 | 44 | 34 | 75 |
| 58 | 26 | 48 | 36 | 77 |
| 60 | 8 41 | 53 | 3 38 | 81 |
| S | | | | |

| Lat. ° | Sunset h m | Twil. m | Moonset h m | Diff. m |
|---|---|---|---|---|
| N | | | | |
| 70 | □ | □ | 16 48 | 102 |
| 68 | □ | □ | 40 | 95 |
| 66 | 22 34 | //// | 33 | 90 |
| 64 | 21 52 | //// | 26 | 86 |
| 62 | 24 | 120 | 22 | 82 |
| 60 | 21 02 | 80 | 17 | 79 |
| 58 | 20 44 | 65 | 13 | 77 |
| 56 | 30 | 57 | 10 | 74 |
| 54 | 17 | 51 | 06 | 73 |
| 52 | 20 06 | 45 | 04 | 70 |
| 50 | 19 57 | 42 | 16 01 | 69 |
| 45 | 36 | 36 | 15 55 | 66 |
| 40 | 20 | 32 | 50 | 63 |
| 35 | 19 07 | 29 | 47 | 59 |
| 30 | 18 55 | 27 | 43 | 58 |
| 20 | 34 | 24 | 37 | 54 |
| 10 | 17 | 23 | 32 | 50 |
| 0 | 18 01 | 22 | 27 | 47 |
| 10 | 17 44 | 23 | 22 | 44 |
| 20 | 27 | 24 | 16 | 42 |
| 30 | 17 08 | 26 | 10 | 38 |
| 35 | 16 57 | 28 | 07 | 35 |
| 40 | 44 | 30 | 15 03 | 33 |
| 45 | 28 | 33 | 14 59 | 30 |
| 50 | 10 | 37 | 53 | 27 |
| 52 | 16 01 | 39 | 51 | 25 |
| 54 | 15 51 | 42 | 48 | 23 |
| 56 | 40 | 45 | 45 | 21 |
| 58 | 27 | 49 | 42 | 19 |
| 60 | 15 12 | 54 | 14 38 | 17 |
| S | | | | |



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## CONVERSION OF ARC TO TIME

| ° | h m | ° | h m | ° | h m | ° | h m | ° | h m | ° | h m | ′ | m s | ″ | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 0 | 60 | 4 0 | 120 | 8 0 | 180 | 12 0 | 240 | 16 0 | 300 | 20 0 | 0 | 0 0 | 0 | 0.00 |
| 1 | 0 4 | 61 | 4 4 | 121 | 8 4 | 181 | 12 4 | 241 | 16 4 | 301 | 20 4 | 1 | 0 4 | 1 | 0.07 |
| 2 | 0 8 | 62 | 4 8 | 122 | 8 8 | 182 | 12 8 | 242 | 16 8 | 302 | 20 8 | 2 | 0 8 | 2 | 0.13 |
| 3 | 0 12 | 63 | 4 12 | 123 | 8 12 | 183 | 12 12 | 243 | 16 12 | 303 | 20 12 | 3 | 0 12 | 3 | 0.20 |
| 4 | 0 16 | 64 | 4 16 | 124 | 8 16 | 184 | 12 16 | 244 | 16 16 | 304 | 20 16 | 4 | 0 16 | 4 | 0.27 |
| 5 | 0 20 | 65 | 4 20 | 125 | 8 20 | 185 | 12 20 | 245 | 16 20 | 305 | 20 20 | 5 | 0 20 | 5 | 0.33 |
| 6 | 0 24 | 66 | 4 24 | 126 | 8 24 | 186 | 12 24 | 246 | 16 24 | 306 | 20 24 | 6 | 0 24 | 6 | 0.40 |
| 7 | 0 28 | 67 | 4 28 | 127 | 8 28 | 187 | 12 28 | 247 | 16 28 | 307 | 20 28 | 7 | 0 28 | 7 | 0.47 |
| 8 | 0 32 | 68 | 4 32 | 128 | 8 32 | 188 | 12 32 | 248 | 16 32 | 308 | 20 32 | 8 | 0 32 | 8 | 0.53 |
| 9 | 0 36 | 69 | 4 36 | 129 | 8 36 | 189 | 12 36 | 249 | 16 36 | 309 | 20 36 | 9 | 0 36 | 9 | 0.60 |
| 10 | 0 40 | 70 | 4 40 | 130 | 8 40 | 190 | 12 40 | 250 | 16 40 | 310 | 20 40 | 10 | 0 40 | 10 | 0.67 |
| 11 | 0 44 | 71 | 4 44 | 131 | 8 44 | 191 | 12 44 | 251 | 16 44 | 311 | 20 44 | 11 | 0 44 | 11 | 0.73 |
| 12 | 0 48 | 72 | 4 48 | 132 | 8 48 | 192 | 12 48 | 252 | 16 48 | 312 | 20 48 | 12 | 0 48 | 12 | 0.80 |
| 13 | 0 52 | 73 | 4 52 | 133 | 8 52 | 193 | 12 52 | 253 | 16 52 | 313 | 20 52 | 13 | 0 52 | 13 | 0.87 |
| 14 | 0 56 | 74 | 4 56 | 134 | 8 56 | 194 | 12 56 | 254 | 16 56 | 314 | 20 56 | 14 | 0 56 | 14 | 0.93 |
| 15 | 1 0 | 75 | 5 0 | 135 | 9 0 | 195 | 13 0 | 255 | 17 0 | 315 | 21 0 | 15 | 1 0 | 15 | 1.00 |
| 16 | 1 4 | 76 | 5 4 | 136 | 9 4 | 196 | 13 4 | 256 | 17 4 | 316 | 21 4 | 16 | 1 4 | 16 | 1.07 |
| 17 | 1 8 | 77 | 5 8 | 137 | 9 8 | 197 | 13 8 | 257 | 17 8 | 317 | 21 8 | 17 | 1 8 | 17 | 1.13 |
| 18 | 1 12 | 78 | 5 12 | 138 | 9 12 | 198 | 13 12 | 258 | 17 12 | 318 | 21 12 | 18 | 1 12 | 18 | 1.20 |
| 19 | 1 16 | 79 | 5 16 | 139 | 9 16 | 199 | 13 16 | 259 | 17 16 | 319 | 21 16 | 19 | 1 16 | 19 | 1.27 |
| 20 | 1 20 | 80 | 5 20 | 140 | 9 20 | 200 | 13 20 | 260 | 17 20 | 320 | 21 20 | 20 | 1 20 | 20 | 1.33 |
| 21 | 1 24 | 81 | 5 24 | 141 | 9 24 | 201 | 13 24 | 261 | 17 24 | 321 | 21 24 | 21 | 1 24 | 21 | 1.40 |
| 22 | 1 28 | 82 | 5 28 | 142 | 9 28 | 202 | 13 28 | 262 | 17 28 | 322 | 21 28 | 22 | 1 28 | 22 | 1.47 |
| 23 | 1 32 | 83 | 5 32 | 143 | 9 32 | 203 | 13 32 | 263 | 17 32 | 323 | 21 32 | 23 | 1 32 | 23 | 1.53 |
| 24 | 1 36 | 84 | 5 36 | 144 | 9 36 | 204 | 13 36 | 264 | 17 36 | 324 | 21 36 | 24 | 1 36 | 24 | 1.60 |
| 25 | 1 40 | 85 | 5 40 | 145 | 9 40 | 205 | 13 40 | 265 | 17 40 | 325 | 21 40 | 25 | 1 40 | 25 | 1.67 |
| 26 | 1 44 | 86 | 5 44 | 146 | 9 44 | 206 | 13 44 | 266 | 17 44 | 326 | 21 44 | 26 | 1 44 | 26 | 1.73 |
| 27 | 1 48 | 87 | 5 48 | 147 | 9 48 | 207 | 13 48 | 267 | 17 48 | 327 | 21 48 | 27 | 1 48 | 27 | 1.80 |
| 28 | 1 52 | 88 | 5 52 | 148 | 9 52 | 208 | 13 52 | 268 | 17 52 | 328 | 21 52 | 28 | 1 52 | 28 | 1.87 |
| 29 | 1 56 | 89 | 5 56 | 149 | 9 56 | 209 | 13 56 | 269 | 17 56 | 329 | 21 56 | 29 | 1 56 | 29 | 1.93 |
| 30 | 2 0 | 90 | 6 0 | 150 | 10 0 | 210 | 14 0 | 270 | 18 0 | 330 | 22 0 | 30 | 2 0 | 30 | 2.00 |
| 31 | 2 4 | 91 | 6 4 | 151 | 10 4 | 211 | 14 4 | 271 | 18 4 | 331 | 22 4 | 31 | 2 4 | 31 | 2.07 |
| 32 | 2 8 | 92 | 6 8 | 152 | 10 8 | 212 | 14 8 | 272 | 18 8 | 332 | 22 8 | 32 | 2 8 | 32 | 2.13 |
| 33 | 2 12 | 93 | 6 12 | 153 | 10 12 | 213 | 14 12 | 273 | 18 12 | 333 | 22 12 | 33 | 2 12 | 33 | 2.20 |
| 34 | 2 16 | 94 | 6 16 | 154 | 10 16 | 214 | 14 16 | 274 | 18 16 | 334 | 22 16 | 34 | 2 16 | 34 | 2.27 |
| 35 | 2 20 | 95 | 6 20 | 155 | 10 20 | 215 | 14 20 | 275 | 18 20 | 335 | 22 20 | 35 | 2 20 | 35 | 2.33 |
| 36 | 2 24 | 96 | 6 24 | 156 | 10 24 | 216 | 14 24 | 276 | 18 24 | 336 | 22 24 | 36 | 2 24 | 36 | 2.40 |
| 37 | 2 28 | 97 | 6 28 | 157 | 10 28 | 217 | 14 28 | 277 | 18 28 | 337 | 22 28 | 37 | 2 28 | 37 | 2.47 |
| 38 | 2 32 | 98 | 6 32 | 158 | 10 32 | 218 | 14 32 | 278 | 18 32 | 338 | 22 32 | 38 | 2 32 | 38 | 2.53 |
| 39 | 2 36 | 99 | 6 36 | 159 | 10 36 | 219 | 14 36 | 279 | 18 36 | 339 | 22 36 | 39 | 2 36 | 39 | 2.60 |
| 40 | 2 40 | 100 | 6 40 | 160 | 10 40 | 220 | 14 40 | 280 | 18 40 | 340 | 22 40 | 40 | 2 40 | 40 | 2.67 |
| 41 | 2 44 | 101 | 6 44 | 161 | 10 44 | 221 | 14 44 | 281 | 18 44 | 341 | 22 44 | 41 | 2 44 | 41 | 2.73 |
| 42 | 2 48 | 102 | 6 48 | 162 | 10 48 | 222 | 14 48 | 282 | 18 48 | 342 | 22 48 | 42 | 2 48 | 42 | 2.80 |
| 43 | 2 52 | 103 | 6 52 | 163 | 10 52 | 223 | 14 52 | 283 | 18 52 | 343 | 22 52 | 43 | 2 52 | 43 | 2.87 |
| 44 | 2 56 | 104 | 6 56 | 164 | 10 56 | 224 | 14 56 | 284 | 18 56 | 344 | 22 56 | 44 | 2 56 | 44 | 2.93 |
| 45 | 3 0 | 105 | 7 0 | 165 | 11 0 | 225 | 15 0 | 285 | 19 0 | 345 | 23 0 | 45 | 3 0 | 45 | 3.00 |
| 46 | 3 4 | 106 | 7 4 | 166 | 11 4 | 226 | 15 4 | 286 | 19 4 | 346 | 23 4 | 46 | 3 4 | 46 | 3.07 |
| 47 | 3 8 | 107 | 7 8 | 167 | 11 8 | 227 | 15 8 | 287 | 19 8 | 347 | 23 8 | 47 | 3 8 | 47 | 3.13 |
| 48 | 3 12 | 108 | 7 12 | 168 | 11 12 | 228 | 15 12 | 288 | 19 12 | 348 | 23 12 | 48 | 3 12 | 48 | 3.20 |
| 49 | 3 16 | 109 | 7 16 | 169 | 11 16 | 229 | 15 16 | 289 | 19 16 | 349 | 23 16 | 49 | 3 16 | 49 | 3.27 |
| 50 | 3 20 | 110 | 7 20 | 170 | 11 20 | 230 | 15 20 | 290 | 19 20 | 350 | 23 20 | 50 | 3 20 | 50 | 3.33 |
| 51 | 3 24 | 111 | 7 24 | 171 | 11 24 | 231 | 15 24 | 291 | 19 24 | 351 | 23 24 | 51 | 3 24 | 51 | 3.40 |
| 52 | 3 28 | 112 | 7 28 | 172 | 11 28 | 232 | 15 28 | 292 | 19 28 | 352 | 23 28 | 52 | 3 28 | 52 | 3.47 |
| 53 | 3 32 | 113 | 7 32 | 173 | 11 32 | 233 | 15 32 | 293 | 19 32 | 353 | 23 32 | 53 | 3 32 | 53 | 3.53 |
| 54 | 3 36 | 114 | 7 36 | 174 | 11 36 | 234 | 15 36 | 294 | 19 36 | 354 | 23 36 | 54 | 3 36 | 54 | 3.60 |
| 55 | 3 40 | 115 | 7 40 | 175 | 11 40 | 235 | 15 40 | 295 | 19 40 | 355 | 23 40 | 55 | 3 40 | 55 | 3.67 |
| 56 | 3 44 | 116 | 7 44 | 176 | 11 44 | 236 | 15 44 | 296 | 19 44 | 356 | 23 44 | 56 | 3 44 | 56 | 3.73 |
| 57 | 3 48 | 117 | 7 48 | 177 | 11 48 | 237 | 15 48 | 297 | 19 48 | 357 | 23 48 | 57 | 3 48 | 57 | 3.80 |
| 58 | 3 52 | 118 | 7 52 | 178 | 11 52 | 238 | 15 52 | 298 | 19 52 | 358 | 23 52 | 58 | 3 52 | 58 | 3.87 |
| 59 | 3 56 | 119 | 7 56 | 179 | 11 56 | 239 | 15 56 | 299 | 19 56 | 359 | 23 56 | 59 | 3 56 | 59 | 3.93 |
| 60 | 4 0 | 120 | 8 0 | 180 | 12 0 | 240 | 16 0 | 300 | 20 0 | 360 | 24 0 | 60 | 4 0 | 60 | 4.00 |



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## POLARIS

| LHA ♈ | Corr. | LHA ♈ | Corr. | LHA ♈ | Corr. | LHA ♈ | Corr. | LHA ♈ | Corr. | LHA ♈ | Corr. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° ′ | ′ | ° ′ | ′ | ° ′ | ′ | ° ′ | ′ | ° ′ | ′ | ° ′ | ′ |
| 358 56 | −54 | 89 43 | −26 | 128 40 | +14 | 178 28 | +54 | 270 37 | +26 | 309 39 | −14 |
| 1 02 | −55 | 90 46 | −25 | 129 39 | +15 | 180 37 | +55 | 271 41 | +25 | 310 37 | −15 |
| 3 20 | −56 | 91 48 | −24 | 130 38 | +16 | 182 56 | +56 | 272 43 | +24 | 311 36 | −16 |
| 5 52 | −57 | 92 50 | −23 | 131 37 | +17 | 185 31 | +57 | 273 46 | +23 | 312 35 | −17 |
| 8 45 | −58 | 93 52 | −22 | 132 36 | +18 | 188 27 | +58 | 274 48 | +22 | 313 34 | −18 |
| 12 11 | −59 | 94 53 | −21 | 133 36 | +19 | 191 57 | +59 | 275 49 | +21 | 314 34 | −19 |
| 16 47 | −60 | 95 53 | −20 | 134 37 | +20 | 196 37 | +60 | 276 50 | +20 | 315 34 | −20 |
| 35 41 | −59 | 96 53 | −19 | 135 37 | +21 | 215 51 | +59 | 277 51 | +19 | 316 34 | −21 |
| 40 16 | −58 | 97 53 | −18 | 136 38 | +22 | 220 31 | +58 | 278 51 | +18 | 317 34 | −22 |
| 43 42 | −57 | 98 53 | −17 | 137 39 | +23 | 224 00 | +57 | 279 51 | +17 | 318 35 | −23 |
| 46 35 | −56 | 99 52 | −16 | 138 41 | +24 | 226 56 | +56 | 280 50 | +16 | 319 37 | −24 |
| 49 07 | −55 | 100 51 | −15 | 139 44 | +25 | 229 31 | +55 | 281 49 | +15 | 320 39 | −25 |
| 51 25 | −54 | 101 50 | −14 | 140 46 | +26 | 231 51 | +54 | 282 48 | +14 | 321 41 | −26 |
| 53 31 | −53 | 102 48 | −13 | 141 50 | +27 | 233 59 | +53 | 283 47 | +13 | 322 44 | −27 |
| 55 30 | −52 | 103 47 | −12 | 142 54 | +28 | 236 00 | +52 | 284 46 | +12 | 323 48 | −28 |
| 57 21 | −51 | 104 45 | −11 | 143 58 | +29 | 237 53 | +51 | 285 44 | +11 | 324 52 | −29 |
| 59 07 | −50 | 105 42 | −10 | 145 04 | +30 | 239 40 | +50 | 286 42 | +10 | 325 56 | −30 |
| 60 48 | −49 | 106 40 | − 9 | 146 10 | +31 | 241 23 | +49 | 287 40 | + 9 | 327 02 | −31 |
| 62 25 | −48 | 107 38 | − 8 | 147 16 | +32 | 243 01 | +48 | 288 37 | + 8 | 328 08 | −32 |
| 63 59 | −47 | 108 35 | − 7 | 148 24 | +33 | 244 36 | +47 | 289 35 | + 7 | 329 15 | −33 |
| 65 29 | −46 | 109 32 | − 6 | 149 32 | +34 | 246 08 | +46 | 290 32 | + 6 | 330 22 | −34 |
| 66 57 | −45 | 110 30 | − 5 | 150 42 | +35 | 247 36 | +45 | 291 30 | + 5 | 331 31 | −35 |
| 68 22 | −44 | 111 27 | − 4 | 151 52 | +36 | 249 02 | +44 | 292 27 | + 4 | 332 41 | −36 |
| 69 44 | −43 | 112 24 | − 3 | 153 03 | +37 | 250 26 | +43 | 293 24 | + 3 | 333 51 | −37 |
| 71 05 | −42 | 113 21 | − 2 | 154 16 | +38 | 251 48 | +42 | 294 21 | + 2 | 335 03 | −38 |
| 72 24 | −41 | 114 18 | − 1 | 155 30 | +39 | 253 08 | +41 | 295 18 | + 1 | 336 16 | −39 |
| 73 41 | −40 | 115 15 | 0 | 156 45 | +40 | 254 26 | +40 | 296 15 | 0 | 337 30 | −40 |
| 74 57 | −39 | 116 12 | + 1 | 158 01 | +41 | 255 42 | +39 | 297 12 | − 1 | 338 46 | −41 |
| 76 11 | −38 | 117 09 | + 2 | 159 19 | +42 | 256 58 | +38 | 298 09 | − 2 | 340 03 | −42 |
| 77 24 | −37 | 118 06 | + 3 | 160 39 | +43 | 258 11 | +37 | 299 06 | − 3 | 341 22 | −43 |
| 78 36 | −36 | 119 03 | + 4 | 162 01 | +44 | 259 24 | +36 | 300 03 | − 4 | 342 43 | −44 |
| 79 46 | −35 | 120 00 | + 5 | 163 25 | +45 | 260 35 | +35 | 301 00 | − 5 | 344 06 | −45 |
| 80 56 | −34 | 120 57 | + 6 | 164 51 | +46 | 261 46 | +34 | 301 57 | − 6 | 345 31 | −46 |
| 82 05 | −33 | 121 55 | + 7 | 166 20 | +47 | 262 55 | +33 | 302 55 | − 7 | 346 58 | −47 |
| 83 12 | −32 | 122 52 | + 8 | 167 51 | +48 | 264 03 | +32 | 303 52 | − 8 | 348 28 | −48 |
| 84 19 | −31 | 123 50 | + 9 | 169 26 | +49 | 265 11 | +31 | 304 49 | − 9 | 350 02 | −49 |
| 85 25 | −30 | 124 47 | +10 | 171 04 | +50 | 266 17 | +30 | 305 47 | −10 | 351 39 | −50 |
| 86 31 | −29 | 125 45 | +11 | 172 47 | +51 | 267 23 | +29 | 306 45 | −11 | 353 20 | −51 |
| 87 36 | −28 | 126 43 | +12 | 174 34 | +52 | 268 29 | +28 | 307 43 | −12 | 355 06 | −52 |
| 88 40 | −27 | 127 42 | +13 | 176 27 | +53 | 269 33 | +27 | 308 41 | −13 | 356 57 | −53 |
| 89 43 | | 128 40 | | 178 28 | | 270 37 | | 309 39 | | 358 56 | |

**LHA ♈ measured westward. Refraction not included: Use Table A.**

## ADDITIONAL STARS

| Name | Mag. | SHA | Dec. |
|---|---|---|---|
| | | ° ′ | ° ′ |
| Alkaid . . . . | 1.9 | 153 40 | N49 36 |
| γ Argus . . . | 1.9 | 238 04 | S47 10 |
| δ Can. Maj . † | 2.0 | 253 29 | S26 18 |
| Castor . . . . | 1.6 | 247 16 | N32 01 |
| β Centauri . . | 0.9 | 150 03 | S60 06 |
| El Nath . . † | 1.8 | 279 20 | N28 34 |
| γ Gem . . . † | 1.9 | 261 24 | N16 27 |
| ζ Orionis . . † | 1.9 | 275 32 | S 1 58 |
| Schedir. . . . | 2.1–2.6 | 350 41 | N56 13 |

† The planetary section of the *Astronomical Navigation Tables* may be used for these stars.

May–Aug., 1943



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## STARS

| Alphabetical order | | | | Order of SHA | | | |
|---|---|---|---|---|---|---|---|
| Name | Mag. | SHA | Dec. | SHA | Dec. | RA | Name |
| | | ° ′ | ° ′ | ° ′ | ° ′ | h m | |
| Acamar | 3.4 | 315 59 | S40 32 | 14 31 | N14 54 | 23 02 | Markab |
| **Achernar** 1 | **0.6** | **336 06** | **S57 31** | **16 22** | **S29 55** | **22 55** | **Fomalhaut** |
| **Acrux** 2 | **1.1** | **174 08** | **S62 47** | 28 50 | S47 14 | 22 05 | Al Na'ir |
| Adhara † | 1.6 | 255 54 | S28 54 | 34 39 | N 9 37 | 21 41 | Enif |
| **Aldebaran** 3 | **1.1** | **291 50** | **N16 24** | **50 07** | **N45 05** | **20 40** | **Deneb** |
| Alioth | 1.7 | 167 07 | N56 16 | 54 42 | S56 55 | 20 21 | Peacock |
| Al Na'ir | 2.2 | 28 50 | S47 14 | **63 00** | **N 8 43** | **19 48** | **Altair** |
| Alnilam † | 1.8 | 276 40 | S 1 14 | 77 04 | S26 22 | 18 52 | Nunki |
| Alphard † | 2.2 | 218 48 | S 8 25 | **81 14** | **N38 44** | **18 35** | **Vega** |
| Alphecca † | 2.3 | 126 56 | N26 54 | 84 54 | S34 25 | 18 20 | Kaus Aust. |
| Alpheratz 4 | 2.2 | 358 38 | N28 47 | 91 10 | N51 30 | 17 55 | Etamin |
| Al Suhail | 2.2 | 223 32 | S43 12 | 96 55 | N12 36 | 17 32 | Rasalague |
| **Altair** 5 | **0.9** | **63 00** | **N 8 43** | 97 33 | S37 04 | 17 30 | Shaula |
| **Antares** 6 | **1.2** | **113 31** | **S26 18** | 103 13 | S15 39 | 17 07 | Sabik |
| **Arcturus** 7 | **0.2** | **146 44** | **N19 29** | (109 20) | S68 56 | 16 43 | α Tri. Aust. |
| ε Argus | 1.7 | 234 40 | S59 20 | **113 31** | **S26 18** | **16 26** | **Antares** |
| Bellatrix † | 1.7 | 279 29 | N 6 18 | 120 45 | S22 28 | 15 57 | Dschubba |
| **Betelgeux** 8 | **0.1–1.2** | **271 59** | **N 7 24** | 126 56 | N26 54 | 15 32 | Alphecca |
| **Canopus** 9 | **−0.9** | **264 20** | **S52 40** | (137 17) | N74 24 | 14 51 | Kochab |
| **Capella** 10 | **0.2** | **281 53** | **N45 56** | **141 04** | **S60 36** | **14 36** | **Rigil Kent.** |
| Caph | 2.4 | 358 28 | N58 50 | **146 44** | **N19 29** | **14 13** | **Arcturus** |
| θ Centauri | 2.3 | 149 10 | S36 06 | 149 10 | S36 06 | 14 03 | θ Centauri |
| β Crucis | 1.5 | 168 54 | S59 23 | **159 27** | **S10 52** | **13 22** | **Spica** |
| γ Crucis | 1.6 | 173 00 | S56 48 | 159 35 | N55 14 | 13 22 | Mizar |
| **Deneb** 11 | **1.3** | **50 07** | **N45 05** | 167 07 | N56 16 | 12 52 | Alioth |
| Deneb Kait. † | 2.2 | 349 49 | S18 18 | 168 54 | S59 23 | 12 44 | β Crucis |
| Denebola † | 2.2 | 183 28 | N14 53 | 173 00 | S56 48 | 12 28 | γ Crucis |
| Dschubba | 2.5 | 120 45 | S22 28 | **174 08** | **S62 47** | **12 23** | **Acrux** |
| Dubhe 12 | 2.0 | 194 57 | N62 04 | 183 28 | N14 53 | 11 46 | Denebola |
| Enif | 2.5 | 34 39 | N 9 37 | 194 57 | N62 04 | 11 00 | Dubhe |
| Etamin | 2.4 | 91 10 | N51 30 | **208 40** | **N12 15** | **10 05** | **Regulus** |
| **Fomalhaut** 13 | **1.3** | **16 22** | **S29 55** | 218 48 | S 8 25 | 9 25 | Alphard |
| Hamal † | 2.2 | 329 01 | N23 12 | (221 52) | S69 29 | 9 13 | Miaplacidus |
| Kaus Aust. | 2.0 | 84 54 | S34 25 | 223 32 | S43 12 | 9 06 | Al Suhail |
| Kochab | 2.2 | (137 17) | N74 24 | 234 40 | S59 20 | 8 21 | ε Argus |
| Marfak | 1.9 | 309 56 | N49 39 | **244 33** | **N28 10** | **7 42** | **Pollux** |
| Markab | 2.6 | 14 31 | N14 54 | **245 55** | **N 5 22** | **7 36** | **Procyon** |
| Miaplacidus | 1.8 | (221 52) | S69 29 | 255 54 | S28 54 | 6 56 | Adhara |
| Mizar | 2.4 | 159 35 | N55 14 | **259 21** | **S16 38** | **6 43** | **Sirius** |
| Nunki | 2.1 | 77 04 | S26 22 | **264 20** | **S52 40** | **6 23** | **Canopus** |
| Peacock 14 | 2.1 | 54 42 | S56 55 | **271 59** | **N 7 24** | **5 52** | **Betelgeux** |
| **Polaris** | **2.1** | **(333 51)** | **N88 59** | 276 40 | S 1 14 | 5 33 | Alnilam |
| **Pollux** 15 | **1.2** | **244 33** | **N28 10** | 279 29 | N 6 18 | 5 22 | Bellatrix |
| **Procyon** 16 | **0.5** | **245 55** | **N 5 22** | **281 53** | **N45 56** | **5 12** | **Capella** |
| Rasalague † | 2.1 | 96 55 | N12 36 | **282 03** | **S 8 16** | **5 12** | **Rigel** |
| **Regulus** 17 | **1.3** | **208 40** | **N12 15** | **291 50** | **N16 24** | **4 33** | **Aldebaran** |
| **Rigel** 18 | **0.3** | **282 03** | **S 8 16** | 309 56 | N49 39 | 3 20 | Marfak |
| **Rigil Kent.** 19 | **0.3** | **141 04** | **S60 36** | 315 59 | S40 32 | 2 56 | Acamar |
| Ruchbah | 2.8 | 339 29 | N59 56 | 329 01 | N23 12 | 2 04 | Hamal |
| Sabik | 2.6 | 103 13 | S15 39 | **(333 51)** | **N88 59** | **1 45** | **Polaris** |
| Shaula | 1.7 | 97 33 | S37 04 | **336 06** | **S57 31** | **1 36** | **Achernar** |
| **Sirius** 20 | **−1.6** | **259 21** | **S16 38** | 339 29 | N59 56 | 1 22 | Ruchbah |
| **Spica** 21 | **1.2** | **159 27** | **S10 52** | 349 49 | S18 18 | 0 41 | Deneb Kait. |
| α Tri. Aust. | 1.9 | (109 20) | S68 56 | 358 28 | N58 50 | 0 06 | Caph |
| **Vega** 22 | **0.1** | **81 14** | **N38 44** | 358 38 | N28 47 | 0 05 | Alpheratz |

SHA = 360° − RA    GHA* = GHA ♈ + SHA*    May-Aug., 1943



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## INTERPOLATION OF GHA

| SUN, PLANETS, ♈ | | | | | | MOON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Int. | Corr. | Int. | Corr. | Int. | Corr. | Int. | Corr. | Int. | Corr. | Int. | Corr. |
| m s | ° ′ | m s | ° ′ | m s | ° ′ | m s | ° ′ | m s | ° ′ | m s | ° ′ |
| 00 00 | 0 00 | 03 17 | 0 50 | 06 37 | 1 40 | 00 00 | 0 00 | 03 20 | 0 49 | 06 39 | 1 37 |
| 01 | 0 01 | 21 | 0 51 | 41 | 1 41 | 02 | 0 01 | 24 | 0 50 | 43 | 1 38 |
| 05 | 0 02 | 25 | 0 52 | 45 | 1 42 | 06 | 0 02 | 29 | 0 51 | 47 | 1 39 |
| 09 | 0 03 | 29 | 0 53 | 49 | 1 43 | 10 | 0 03 | 33 | 0 52 | 52 | 1 40 |
| 13 | 0 04 | 33 | 0 54 | 53 | 1 44 | 14 | 0 04 | 37 | 0 53 | 56 | 1 41 |
| 17 | 0 05 | 37 | 0 55 | 57 | 1 45 | 18 | 0 05 | 41 | 0 54 | 07 00 | 1 42 |
| 21 | 0 06 | 41 | 0 56 | 07 01 | 1 46 | 22 | 0 06 | 45 | 0 55 | 04 | 1 43 |
| 25 | 0 07 | 45 | 0 57 | 05 | 1 47 | 26 | 0 07 | 49 | 0 56 | 08 | 1 44 |
| 29 | 0 08 | 49 | 0 58 | 09 | 1 48 | 31 | 0 08 | 53 | 0 57 | 12 | 1 45 |
| 33 | 0 09 | 53 | 0 59 | 13 | 1 49 | 35 | 0 09 | 58 | 0 58 | 16 | 1 46 |
| 37 | 0 10 | 57 | 1 00 | 17 | 1 50 | 39 | 0 10 | 04 02 | 0 59 | 20 | 1 47 |
| 41 | 0 11 | 04 01 | 1 01 | 21 | 1 51 | 43 | 0 11 | 06 | 1 00 | 25 | 1 48 |
| 45 | 0 12 | 05 | 1 02 | 25 | 1 52 | 47 | 0 12 | 10 | 1 01 | 29 | 1 49 |
| 49 | 0 13 | 09 | 1 03 | 29 | 1 53 | 51 | 0 13 | 14 | 1 02 | 33 | 1 50 |
| 53 | 0 14 | 13 | 1 04 | 33 | 1 54 | 55 | 0 14 | 18 | 1 03 | 37 | 1 51 |
| 57 | 0 15 | 17 | 1 05 | 37 | 1 55 | 01 00 | 0 15 | 22 | 1 04 | 41 | 1 52 |
| 01 01 | 0 16 | 21 | 1 06 | 41 | 1 56 | 04 | 0 16 | 27 | 1 05 | 45 | 1 53 |
| 05 | 0 17 | 25 | 1 07 | 45 | 1 57 | 08 | 0 17 | 31 | 1 06 | 49 | 1 54 |
| 09 | 0 18 | 29 | 1 08 | 49 | 1 58 | 12 | 0 18 | 35 | 1 07 | 54 | 1 55 |
| 13 | 0 19 | 33 | 1 09 | 53 | 1 59 | 16 | 0 19 | 39 | 1 08 | 58 | 1 56 |
| 17 | 0 20 | 37 | 1 10 | 57 | 2 00 | 20 | 0 20 | 43 | 1 09 | 08 02 | 1 57 |
| 21 | 0 21 | 41 | 1 11 | 08 01 | 2 01 | 24 | 0 21 | 47 | 1 10 | 06 | 1 58 |
| 25 | 0 22 | 45 | 1 12 | 05 | 2 02 | 29 | 0 22 | 51 | 1 11 | 10 | 1 59 |
| 29 | 0 23 | 49 | 1 13 | 09 | 2 03 | 33 | 0 23 | 56 | 1 12 | 14 | 2 00 |
| 33 | 0 24 | 53 | 1 14 | 13 | 2 04 | 37 | 0 24 | 05 00 | 1 13 | 18 | 2 01 |
| 37 | 0 25 | 57 | 1 15 | 17 | 2 05 | 41 | 0 25 | 04 | 1 14 | 23 | 2 02 |
| 41 | 0 26 | 05 01 | 1 16 | 21 | 2 06 | 45 | 0 26 | 08 | 1 15 | 27 | 2 03 |
| 45 | 0 27 | 05 | 1 17 | 25 | 2 07 | 49 | 0 27 | 12 | 1 16 | 31 | 2 04 |
| 49 | 0 28 | 09 | 1 18 | 29 | 2 08 | 53 | 0 28 | 16 | 1 17 | 35 | 2 05 |
| 53 | 0 29 | 13 | 1 19 | 33 | 2 09 | 58 | 0 29 | 20 | 1 18 | 39 | 2 06 |
| 57 | 0 30 | 17 | 1 20 | 37 | 2 10 | 02 02 | 0 30 | 25 | 1 19 | 43 | 2 07 |
| 02 01 | 0 31 | 21 | 1 21 | 41 | 2 11 | 06 | 0 31 | 29 | 1 20 | 47 | 2 08 |
| 05 | 0 32 | 25 | 1 22 | 45 | 2 12 | 10 | 0 32 | 33 | 1 21 | 52 | 2 09 |
| 09 | 0 33 | 29 | 1 23 | 49 | 2 13 | 14 | 0 33 | 37 | 1 22 | 56 | 2 10 |
| 13 | 0 34 | 33 | 1 24 | 53 | 2 14 | 18 | 0 34 | 41 | 1 23 | 09 00 | 2 11 |
| 17 | 0 35 | 37 | 1 25 | 57 | 2 15 | 22 | 0 35 | 45 | 1 24 | 04 | 2 12 |
| 21 | 0 36 | 41 | 1 26 | 09 01 | 2 16 | 26 | 0 36 | 49 | 1 25 | 08 | 2 13 |
| 25 | 0 37 | 45 | 1 27 | 05 | 2 17 | 31 | 0 37 | 54 | 1 26 | 12 | 2 14 |
| 29 | 0 38 | 49 | 1 28 | 09 | 2 18 | 35 | 0 38 | 58 | 1 27 | 16 | 2 15 |
| 33 | 0 39 | 53 | 1 29 | 13 | 2 19 | 39 | 0 39 | 06 02 | 1 28 | 21 | 2 16 |
| 37 | 0 40 | 57 | 1 30 | 17 | 2 20 | 43 | 0 40 | 06 | 1 29 | 25 | 2 17 |
| 41 | 0 41 | 06 01 | 1 31 | 21 | 2 21 | 47 | 0 41 | 10 | 1 30 | 29 | 2 18 |
| 45 | 0 42 | 05 | 1 32 | 25 | 2 22 | 51 | 0 42 | 14 | 1 31 | 33 | 2 19 |
| 49 | 0 43 | 09 | 1 33 | 29 | 2 23 | 55 | 0 43 | 18 | 1 32 | 37 | 2 20 |
| 53 | 0 44 | 13 | 1 34 | 33 | 2 24 | 03 00 | 0 44 | 23 | 1 33 | 41 | 2 21 |
| 57 | 0 45 | 17 | 1 35 | 37 | 2 25 | 04 | 0 45 | 27 | 1 34 | 45 | 2 22 |
| 03 01 | 0 46 | 21 | 1 36 | 41 | 2 26 | 08 | 0 46 | 31 | 1 35 | 50 | 2 23 |
| 05 | 0 47 | 25 | 1 37 | 45 | 2 27 | 12 | 0 47 | 35 | 1 36 | 54 | 2 24 |
| 09 | 0 48 | 29 | 1 38 | 49 | 2 28 | 16 | 0 48 | 39 | 1 37 | 58 | 2 25 |
| 13 | 0 49 | 33 | 1 39 | 53 | 2 29 | 20 | 0 49 | 43 | | 10 00 | |
| 17 | 0 50 | 37 | 1 40 | 57 | 2 30 | 24 | | | | | |
| 21 | | 41 | | 10 00 | | | | | | | |

Correction to be added to GHA for interval of GCT

### DIP

*Subtract* from altitude observed with *sea horizon*.

| Height | Corr. | Height | Corr. | Height | Corr. | Height | Corr. |
|---|---|---|---|---|---|---|---|
| *Ft.* | ′ | *Ft.* | ′ | *Ft.* | ′ | *Ft.* | ′ |
| 0 | 1 | 160 | 13 | 620 | 25 | 1380 | 37 |
| 2 | 2 | 180 | 14 | 670 | 26 | 1460 | 38 |
| 6 | 3 | 210 | 15 | 730 | 27 | 1540 | 39 |
| 12 | 4 | 250 | 16 | 780 | 28 | 1620 | 40 |
| 21 | 5 | 280 | 17 | 840 | 29 | 1700 | 41 |
| 31 | 6 | 310 | 18 | 900 | 30 | 1790 | 42 |
| 43 | 7 | 350 | 19 | 960 | 31 | 1870 | 43 |
| 58 | 8 | 390 | 20 | 1030 | 32 | 1960 | 44 |
| 75 | 9 | 430 | 21 | 1090 | 33 | 2060 | 45 |
| 93 | 10 | 480 | 22 | 1160 | 34 | 2150 | 46 |
| 114 | 11 | 520 | 23 | 1230 | 35 | 2250 | 47 |
| 137 | 12 | 570 | 24 | 1310 | 36 | 2340 | 48 |
| 162 | | 620 | | 1380 | | 2440 | |

### REFRACTION

A. *Total correction.*—For use with H. O. 208, H. O. 209, H. O. 211, H. O. 214, and the Polaris Table. Subtract from observed altitude.

| Height in feet | Observed altitude | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5° | 10° | 15° | 20° | 30° | 45° | 60° |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| 0 | 10 | 5 | 4 | 3 | 2 | 1 | 1 |
| 5,000 | 8 | 5 | 3 | 2 | 1 | 1 | 0 |
| 10,000 | 7 | 4 | 3 | 2 | 1 | 1 | 0 |
| 15,000 | 6 | 3 | 2 | 2 | 1 | 1 | 0 |
| 20,000 | 5 | 3 | 2 | 1 | 1 | 1 | 0 |
| 25,000 | 4 | 2 | 2 | 1 | 1 | 0 | 0 |
| 30,000 | 3 | 2 | 1 | 1 | 1 | 0 | 0 |
| 35,000 | 3 | 2 | 1 | 1 | 1 | 0 | 0 |
| 40,000 | 2 | 1 | 1 | 1 | 0 | 0 | 0 |



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# GLOSSARY OF NAVIGATION TERMS

**AGONIC LINE**—Line connecting points of zero magnetic variation.

**AIR NAVIGATION**—Determining, and keeping an account of, an aircraft's position while flying from point to point.

**Pilotage**—Navigation with reference to visible ground objects.

**Dead Reckoning** — Navigation based on known values of time, speed, distance and direction.

**Radio**—Navigation by use of radio aids such as radio ranges, marker beacons and direction finding stations.

**Celestial**—Navigation with reference to the positions of the celestial bodies.

**AIR SPEED**—Speed of an aircraft with reference to the surrounding air.

**Indicated**—Air speed shown by the air speed indicator.

**Calibrated**—Indicated air speed corrected for instrument and installation errors.

**True**—Calibrated air speed corrected for temperature and pressure (altitude).

**ALTITUDE (celestial)** — Angular distance from the celestial horizon to the center of a celestial body measured upon the vertical circle passing through the body. It is also the angle at the center of the earth subtended by this arc.

**ALTITUDE INTERCEPT**—Angular difference between computed altitude of a body and its observed (true) altitude. Distance (in nautical miles) of observer's line of position from his assumed position.

**ASTRONOMICAL TRIANGLE**—Triangle on the celestial sphere bounded by the hour and vertical circles through a body, and the observer's (celestial) meridian.

**AZIMUTH**—The angle at the zenith (or arc of the horizon) measured from the observer's meridian to the vertical circle passing through a body. It is measured from the North branch of the meridian if observer is in North latitude and from the South branch if he is in South latitude, and toward the East if body is rising or West if body is setting, through 180°.

**AXIS**

**Earth**—Centerline about which the earth turns.

**Celestial Sphere**—Earth's axis extended to the celestial sphere.

**BEARING**—Direction of one object to another measured clockwise through 360°.

**Relative**—Direction of an object with reference to the centerline of the aircraft.

**True**—Direction of an object with reference to true North.

**Magnetic**—Direction of an object with reference to magnetic North.

**CHART**—Representation of the earth's surface, or a portion thereof, on a flat surface. Maps are primarily concerned with the land, while charts usually supply information about water and land bounded by water.

**CIRCLE OF EQUAL ALTITUDE**—Circle on the earth's surface from which any observer will observe a given celestial body at the same altitude for a given instant of time.

**COLLIMATION**—Act of bringing a celestial body and bubble into coincidence in the field of an aircraft octant.

**COURSE**—Intended track.

**True**—Course measured with reference to true North.

**Magnetic**—Course measured with reference to magnetic North.

**Compass**—Course measured with reference to compass North (direction in which compass needle points).



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**DECLINATION**—Arc of the hour circle measured from the equinoctial to the celestial body, North or South through 90°.

**DEVIATION**—Influence of local magnetic disturbances within the aircraft on the magnetic compass needle, causing the needle to point to other than magnetic North. The angular difference between magnetic North and compass North, which changes with heading of aircraft.

**DIP**

**Compass**—Deflection of compass needle from the horizontal due to the influence of the vertical component of the earth's magnetic field.

**Celestial**—A sextant altitude correction caused by depression of the horizon in proportion to aircraft's height. Must be considered when using sea horizon as horizontal reference plane.

**DRIFT**—Effect of crosswind. (Also see DRIFT ANGLE.)

**DRIFT ANGLE**—Angular difference between heading and track.

**DRIFT CORRECTION ANGLE**—Angular difference between heading and course.

**ECLIPTIC**—Path of earth in its revolution around the sun, or path of sun in its *apparent* revolution around the earth.

**EQUATOR**—Great circle on the earth's surface lying midway between the poles. Used as reference line for the measurement of latitude.

**EQUINOCTIAL**—Projection of the earth's equator onto the celestial sphere. Reference line for the measurement of declination.

**EQUINOX**—Intersection of the equinoctial and the ecliptic.

**Vernal**—Point where the sun changes declination from South to North (First Point of Aries).

**Autumnal**—Point where the sun changes declination from North to South (First Point of Libra).

**FIRST POINT OF ARIES**—(See Equinox, Vernal).

**FIX**—Geographical location of aircraft as determined by two or more lines of position.

**GEOGRAPHICAL POSITION**—Point where a line connecting the center of the earth with a body would intersect the surface of the earth.

**GREAT CIRCLE**—Circle on the surface of a sphere, the plane of which passes through the center of the sphere.

**GROUND SPEED**—Speed of the aircraft with reference to the ground.

**HEADING**—Direction in which the aircraft is pointed.

**True**—Heading with reference to true North.

**Magnetic**—Heading with reference to magnetic North.

**Compass**—Heading with reference to compass North.

**HORIZON**

**Celestial (true)**—Great circle on the celestial sphere, the plane of which is perpendicular to the zenith-nadir line.

**Observer's**—Plane passing through the eye of the observer, parallel to the celestial horizon.

**Note:** Celestial horizon and observer's horizon are so close, relatively, that for observations of all celestial bodies other than the moon they are considered to coincide.

**HOUR ANGLE**

**Local**—An arc of the equinoctial measured from the observer's meridian (upper branch) to the hour circle passing through a celestial body, over West through 360°.

**Note:** When used as an argument to enter H. O. 214 (or any other table of precomputed solutions of the astronomical triangle), local hour angle is measured only through 180° and is then named *East* if the body is *East* of the observer, and *West* if it is *West* of him.

**Greenwich**—Arc of the equinoctial measured from the Greenwich meridian to the hour circle passing through the celestial body, over West through 360°.

**Sidereal**—Arc of the equinoctial measured from the First Point of Aries to the hour



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circle passing through the body, over West through 360°.

**HOUR CIRCLE**—Great circle on the celestial sphere passing through both poles and a celestial body.

**INDEX CORRECTION**—Angular amount by which the counter on a sextant or octant is in error in recording the altitude of a body due to misalignment of index glass and arm, slippage or other mechanical faults within the instrument.

**INSTRUMENT CORRECTION**—Total angular correction which must be applied to each altitude reading because of index and bubble error in a sextant or octant.

**ISOGONIC LINE**—Line connecting points of equal magnetic variation.

**KNOT**—Unit of speed equal to one nautical mile per hour.

**LATITUDE**—Angular distance North and South of the equator measured in degrees of arc from 0° to 90°.

**LINE OF POSITION**

**General**—Straight line on the earth's surface representing all possible positions of an aircraft at a given instant of time.

**Celestial**—Small arc of a circle of equal altitude on which the observer is located. For short distances this arc is considered to be a straight line.

**LONGITUDE**—Angular distance East and West of the prime meridian, measured in degrees of arc from 0° to 180°.

**MAP**—(see CHART).

**MERIDIAN**—Great circle on the earth's surface passing through both poles. Projected onto the celestial sphere it becomes a celestial meridian.

**Prime (Greenwich)**—Meridian used as reference line for the measurement of longitude. Passes through Greenwich, England.

**Observer's**—Meridian passing through the observer's position.

**NADIR**—Point on the celestial sphere directly beneath the observer.

**NAUTICAL MILE**—Unit of distance equal to approximately 6080 feet, or one minute of arc of a great circle on the earth's surface, hence one minute of latitude, or one minute of longitude at the equator.

**OCTANT**—Instrument used to measure the altitudes of celestial bodies. Specifically, one capable of measuring angles up to and including 90°. However, as commonly used, the term is synonymous with the term "sextant."

**PARALLAX**—Angle subtended at the center of the moon by the radius of the earth.

**PARALLEL** (of latitude)—Division of latitude parallel to the equator. Parallels are small circles.

**PELORUS**—A dummy compass card equipped with sighting vanes for taking bearings on terrestrial or celestial objects.

**POLES**

**Earth**—Ends of the earth's axis.

**Celestial**—Earth's poles projected onto the celestial sphere.

**POLAR DISTANCE**—Arc of the hour circle intercepted between a celestial body and the elevated pole. One side of the astronomical triangle. Equal to 90° minus declination of the body.

**RADIUS OF ACTION**—Distance an aircraft can fly with a given amount of fuel and under given wind conditions and still return to the same or an alternate base.

**RHUMB LINE**—Line which intersects all meridians at the same angle.

**REFRACTION**

**General**—Bending of light as it passes from one medium to another of different density.

**Celestial**—Bending of light rays from a celestial body on entering the earth's atmosphere, causing an error in measuring the altitude of the body.

**RIGHT ASCENSION**—An arc of the equinoctial lying between the First Point of Aries and the hour circle passing through a body, measured East through 24 hours.

**SOLSTICE**—Point of maximum declination of the sun. If maximum northerly declination it is known as summer solstice; if maximum southerly declination, it is winter solstice.



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**SPHERE**

**General**—A body bounded by a surface, all points of which are equidistant from a point within called the center.

**Celestial**—A theoretical globe of infinite radius whose point of origin is considered to be the center of the earth.

**SEMIDIAMETER**—A sextant altitude correction which must be taken into account when using either the upper or lower limb (edge) of the sun or moon to achieve collimation. Ordinarily, therefore, this correction applies only to observations made with a marine sextant.

**SEXTANT**—Same as Octant except that it is capable of measuring angles up to 120°. Term commonly used to signify any type of altitude-measuring instrument.

**SMALL CIRCLE**—Circle on the earth's surface, the plane of which does not pass through the center of the earth.

**STATUTE MILE**—An arbitrary unit of distance equal to 5280 feet.

**TRACK**—Actual path made good by an aircraft over the ground.

**True**—Track measured with reference to true North.

**Magnetic**—Track measured with reference to magnetic North.

**Compass**—Track measured with reference to compass North.

**Great Circle**—Shortest distance between two points on the earth's surface.

**TIME**—Lapse between two events.

**Solar (Apparent)**—Time derived from passage of the true sun.

**Civil (Mean)**—Time derived from passage of the mean sun (an imaginary sun which is considered to move along the equinoctial at a constant rate throughout the year).

**Sidereal (Star)**—Time derived from passage of the First Point of Aries (or a star).

**VARIATION** — Angular difference between true North and magnetic North. Caused by the fact that true (geographic) North and magnetic North are not located at the same position on the earth's surface. Changes with aircraft's geographical position.

**VECTOR**—Any quantity having direction and magnitude which are represented graphically by a directed straight line segment. In navigation the principal vector quantities considered are heading and air speed of the aircraft, track (intended or actual) and ground speed, and the direction and velocity of the wind.

**VERTICAL CIRCLE** — Great circle on the celestial sphere passing through zenith, nadir and a celestial body.

**ZENITH**—Point on the celestial sphere directly above the observer.

**Distance**—Arc of the vertical circle lying between the celestial body and zenith. Equal to 90° minus altitude of the body. One side of the astronomical triangle.

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## ABBREVIATIONS

| | |
|---|---|
| a | Altitude intercept |
| alt. (or h) | Altitude |
| A.M. | Antemeridian or forenoon |
| A.S. | Air speed |
| Az | Azimuth |
| C | Course |
| Cel. | Celestial |
| C.A.S. | Calibrated air speed |
| CC | Compass course |
| CE | Compass error |
| CH | Compass heading |
| Corr. | Correction |
| D.A. | Drift angle |
| dec. | Declination |
| dist. | Distance |
| DLo | Difference of longitude |
| Dep. | Departure |
| Dev. | Deviation |
| DL | Difference of latitude |
| DR | Dead Reckoning |
| E | East |
| ETA | Estimated time of arrival |



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| | |
|---|---|
| G.P. | Geographical position |
| GAT | Greenwich apparent time |
| GCT | Greenwich civil time |
| GHA | Greenwich hour angle |
| G.S. | Ground speed |
| GST | Greenwich sidereal time |
| HA | Hour angle |
| h(H) | Altitude |
| $h_c$ | Computed altitude |
| $h_o$ | True (observed) altitude |
| $h_s$ | Sextant or octant altitude |
| I.A.S. | Indicated air speed |
| I.C. | Instrument correction |
| Kts | Knots |
| Lat. | Latitude |
| Long. | Longitude |
| m | Difference of meridional parts |
| M | Meridional parts |
| min. | minutes (of time) |
| MH | Magnetic heading |
| Mag. | Magnetic |
| MC | Magnetic course |
| m.p.h. | Miles per hour (statute miles) |
| MTr | Meridian transit |
| N | North |
| Na. | Nadir |
| L.O.P. | Line of position |
| NM | Nautical miles |
| P | Pole |
| Pd | Polar distance |
| par. | Parallax |
| P.M. | Postmeridian or afternoon |
| $P_n$ | North celestial pole |
| PN | Point of no return |
| $P_s$ | South celestial pole |
| R.A. | Radius of action |
| RA | Right ascension |
| R.B. | Relative bearing |
| Ref. | Refraction |
| S | South |
| SD | Semidiameter |
| SHA | Sidereal hour angle |
| TH | True heading |
| T.A.S. | True air speed |
| Temp. | Temperature |
| TC | True course |
| Tk | Track |
| T/t | Time to turn |
| Var. | Variation |
| W | West |
| Z | Zenith |
| Zd | Zenith distance |
| ZD | Zone description |
| $Z_n$ | True bearing of a celestial body (measured from true north through 360°) |
| ZT | Zone time |

☆

## SYMBOLS

| | |
|---|---|
| $\odot$ | The sun |
| ☾ | The moon |
| * | A star or planet |
| $\underline{\odot}$ | Altitude lower limb |
| $\overline{\odot}$ | Altitude upper limb |
| ♈ | Vernal Equinox or First Point of Aries |
| ø | Bearing (Phi) |
| $\lambda$ | Longitude (Lambda) |
| $\beta$ | Beta |
| $\Delta$ | Delta |
| $\gamma$ | Gamma |

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## POSITION LEGEND

1—DR position
2—Approximate fix
3—Fix



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## ANSWERS TO PROBLEM WORK

Exact agreement cannot be expected with problems involving vector diagrams and chart work since the plotted angles or information obtained on a computer may vary slightly. Therefore, altitudes should be within ± 50 feet; air speed ± 2 knots or 2 m.p.h.; latitude and longitude ± 5 minutes, and courses and bearings within one degree of the results tabulated herewith.

| PROBLEM WORK NO. 1<br>CHART DRAWINGS | PROBLEM WORK NO. 2<br>MERCATOR CHART | PROBLEM WORK NO. 3<br>AIRCRAFT COMPASS DRAWING |
|---|---|---|

| PROBLEM WORK NO. 4<br>ALTIMETER CORRECTION | | PROBLEM WORK NO. 5<br>AIR SPEED CORRECTION | | | |
|---|---|---|---|---|---|
| No. | TRUE ALTITUDE | No. | I.A.S. (m.p.h.) | C.A.S. (knots) | T.A.S. (knots) |
| 1 | 8300′ | 1 | | 129 | 154 |
| 2 | 3080′ | 2 | | 146 | 164 |
| 3 | 23,300′ | 3 | 188 | 169 | |
| 4 | 11,200′ | 4 | 187 | 168 | |
| 5 | 5180′ | 5 | | 149 | 164 |
| 6 | 19,100′ | 6 | 179 | 160 | |
| 7 | 1990′ | 7 | | 132 | 144 |
| 8 | 9000′ | 8 | 185 | 165 | |
| 9 | 17,750′ | 9 | | 144 | 146 |
| 10 | 13,850′ | 10 | | 126 | 131 |
| 11 | 6170′ | 11 | | 137 | 163 |
| 12 | 1410′ | 12 | 200 | 177 | |
| 13 | 2830′ | 13 | | 150 | 162 |
| 14 | 10,200′ | 14 | | 161 | 202 |
| 15 | 8500′ | 15 | | 167 | 205 |
| 16 | 6270′ | 16 | | 143 | 148 |
| 17 | 7500′ | 17 | 185 | 166 | |
| 18 | 9950′ | 18 | 187 | 168 | |
| 19 | 8700′ | 19 | | 161 | 178 |
| 20 | 12,200′ | 20 | | 109 | 111 |



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**PROBLEM WORK NO. 6**
**APPLYING COMPASS ERRORS**

| No. | TRUE COURSE | VARIATION | MAGNETIC COURSE | DEVIATION | COMPASS COURSE |
|---|---|---|---|---|---|
| 1 | | 10°E | | | 80° |
| 2 | 270° | | | 3°W | |
| 3 | | | 24° | | 23° |
| 4 | 2° | | | | 346° |
| 5 | | 5°W | | 5°W | |
| 6 | | | 343° | 4°E | |
| 7 | | 0° | 122° | | |
| 8 | 359° | | 346° | | |
| 9 | | 10°W | | 1°E | |
| 10 | | 15°E | 100° | | |
| 11 | 223° | | 237° | | |
| 12 | | 9°E | | | 219° |
| 13 | 147° | | | | 154° |
| 14 | | 11°W | | 9°E | |
| 15 | | | 315° | 5°W | |
| 16 | | | 201° | | 200° |
| 17 | 312° | | | 6°W | |
| 18 | | 8°E | 326° | | |
| 19 | 3° | | | | 343° |
| 20 | | 5°W | | | 100° |

**PROBLEM WORK NO. 7**
**TRACK AND HEADING**

| No. | TRACK TRUE | VAR. | TRACK MAGNETIC | DRIFT | HEADING MAGNETIC | DEV. | HEADING COMPASS | HEADING TRUE |
|---|---|---|---|---|---|---|---|---|
| 1 | | | 103° | | 101° | | 104° | 115° |
| 2 | 231° | | | 4°R | | 2°E | | 227° |
| 3 | | 14°W | | 4°L | 65° | | 68° | |
| 4 | | 10°E | | 6°R | | 0° | | 336° |
| 5 | | | 81° | 3°R | | 7°E | | 93° |
| 6 | 276° | | | 2°R | | 9°W | | 274° |
| 7 | | | 121° | 1°R | 120° | | 124° | |
| 8 | 242° | | | 2°R | | | 223° | 240° |
| 9 | | 16°E | | | 155° | 6°W | | 171° |
| 10 | 209° | | 221° | | | 4°E | | 209° |
| 11 | 173° | | 183° | | | | 185° | 175° |
| 12 | 198° | 16°E | | 4°R | | 5°W | | |
| 13 | 114° | | 131° | | 124° | 4°E | | |
| 14 | | 11°E | | 1°L | 346° | | | 357° |
| 15 | | 14°E | | 1°L | | | 3° | 7° |
| 16 | 300° | | | | 281° | 6°E | | 297° |
| 17 | | 12°W | | | 262° | | 276° | 250° |
| 18 | 222° | | 236° | | 232° | | 237° | |
| 19 | 200° | 24°E | 176° | | | | 190° | |
| 20 | 118° | | | 4°R | | 6°E | | 114° |



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## PROBLEM WORK NO. 8
## TIME—SPEED—DISTANCE

| No. | DISTANCE (Nautical Miles) | No. | SPEED (Knots) | No. | TIME |
|---|---|---|---|---|---|
| 1 | 181.25 | 9 | 118.05 | 16 | 1h26m |
| 2 | 213.11 | 10 | 157.85 | 17 | 1h56m |
| 3 | 347.64 | 11 | 109.12 | 18 | 0h35m |
| 4 | 111.46 | 12 | 142.09 | 19 | 1h20m |
| 5 | 468.05 | 13 | 141.96 | 20 | 1h42m |
| 6 | 240.30 | 14 | 185.36 | | |
| 7 | 284.40 | 15 | 148.15 | | |
| 8 | 152.54 | | | | |

## PROBLEM WORK NO. 9-A VECTOR DIAGRAMS / PROBLEM WORK NO. 9-B VECTOR DIAGRAMS / PROBLEM WORK NO. 10 DOUBLE DRIFT

| No. | HEADING TRUE | HEADING COMPASS | GROUND SPEED | DRIFT | No. | WIND | DRIFT | No. | WIND |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 69° | | 104 | 16°R | 1 | 22°/28 | 10°R | 1 | 168°/11 |
| 2 | 152° | | 102 | 21°R | 2 | 64°/47 | 25°R | 2 | 316°/23 |
| 3 | 155° | | 92 | 15°L | 3 | 236°/27 | 10°R | 3 | 163°/17 |
| 4 | 315° | | 130 | 15°L | 4 | 296°/25 | 12°L | 4 | 102°/40 |
| 5 | 216° | | 141 | 8°L | 5 | 116°/26 | 14°L | 5 | 122°/23 |
| 6 | 162° | | 176 | 14°L | 6 | 119°/19 | 7°L | 6 | 43°/25 |
| 7 | 162° | | 176 | 8°R | 7 | 344°/12 | 6°R | 7 | 180°/19 |
| 8 | 248° | | 125 | 8°L | 8 | 2°/43 | 9°L | 8 | 192°/26 |
| 9 | 45° | | 165 | 8°L | 9 | 59°/41 | 13°R | 9 | 24°/33 |
| 10 | 348° | | 178 | 12°R | 10 | 197°/41 | 16°R | 10 | 339°/25 |
| 11 | 359° | | 158 | 9°L | 11 | 27°/16 | 8°L | 11 | 305°/19 |
| 12 | 24° | | 196 | 8°L | 12 | 161°/30 | 11°L | 12 | 355°/14 |
| 13 | 92° | | 139 | 8°R | 13 | 336°/38 | 12°R | 13 | 193°/41 |
| 14 | 71° | | 132 | 11°L | 14 | 310°/17 | 7°R | 14 | 114°/23 |
| 15 | 335° | | 163 | 5°L | 15 | 142°/36 | 18°L | 15 | 233°/21 |
| 16 | 195° | 192° | 142 | 9°R | 16 | 23°/33 | 12°R | 16 | 41°/25 |
| 17 | 24° | 26° | 151 | 7°R | 17 | 98°/52 | 22°L | 17 | 125°/17 |
| 18 | 82° | 87° | 168 | 6°L | 18 | 264°/22 | 11°L | 18 | 251°/36 |
| 19 | 199° | 185° | 127 | 9°L | 19 | 213°/10 | 4°L | 19 | 136°/18 |
| 20 | 280° | 286° | 140 | 10°L | 20 | 338°/29 | 12°R | 20 | 156°/22 |

## DEAD RECKONING REVIEW TEST NO. 1

4 (a) Magnetic course = 306°. True course = 296°.
  (b) True track = 206°. Compass heading = 197°. Magnetic course = 190°.
  (c) True heading = 29°. Compass course = 15°. Magnetic course = 21°.
5 True altitude = 9300 feet.
6 (a) Calibrated air speed = 158 knots. True air speed = 191 knots.
  (b) True air speed = 193 knots.
7 (a) 05:44 GCT. (b) 118 knots. (c) 690 Nautical miles.
8 (a) Ground speed = 163 knots. True heading = 282°. Drift = 10°L.
  (b) Ground speed = 94 knots. Track = 74°. Drift = 14°R.
  (c) Wind = 313°/56 knots. Drift = 15°L.
9 Wind = 238°/22 knots.
10 Distance out = 529 Nautical miles. Time to turn = 12:21 GCT.



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| PROBLEM WORK NO. 11-A RADIUS OF ACTION TO A FIXED BASE | | | | |
|---|---|---|---|---|
| No. | TRUE HEADING OUT | TRUE HEADING IN | RADIUS OF ACTION | TIME TO TURN |
| 1 | 78° | 266° | 524 | 12:33 |
| 2 | 301° | 139° | 301 | 12:21 |
| 3 | 206° | 10° | 262 | 15:37 |
| 4 | 256° | 65° | 751 | 22:02 |
| 5 | 280° | 82° | 231 | 12:08 |
| 6 | 185° | 37° | 230 | 8:57 |
| 7 | 48° | 234° | 514 | 10:25 |
| 8 | 22° | 238° | 222 | 17:37 |
| 9 | 354° | 227° | 384 | 3:51 |
| 10 | 123° | 328° | 516 | 4:02 |

| PROBLEM WORK NO. 11-B RADIUS OF ACTION TO ALTERNATE BASE | | | | |
|---|---|---|---|---|
| No. | True Heading to Destination | True Heading to Alternate | DISTANCE OUT | TIME TO TURN |
| 1 | 38° | 177° | 293 | 2:39 |
| 2 | 222° | 163° | 57 | :49 |
| 3 | 39° | 249° | 219 | 2:19 |
| 4 | 280° | 137° | 280 | 2:02 |
| 5 | 138° | 281° | 534 | 2:47 |
| 6 | 334° | 227° | 159 | 1:35 |
| 7 | 51° | 158° | 95 | 1:42 |
| 8 | 123° | 332° | 194 | 1:09 |
| 9 | 186° | 284° | 143 | :51 |
| 10 | 296° | 194° | 63 | :38 |

PROBLEM WORK NO. 12
RADIO BEARING DRAWING

PROBLEM WORK NO. 15
CELESTIAL SPHERE

PROBLEM WORK NO. 13
MERCATOR SIGN CORRECTION

PROBLEM WORK NO. 16
ASTRONOMICAL TRIANGLE

| PROBLEM WORK NO. 14 RADIO BEARINGS | | PROBLEM WORK NO. 17 GHA AND DECLINATION | | |
|---|---|---|---|---|
| No. | Mercator Bearing | No. | GHA | DEC. |
| 1 | 54° | 1 | 185°00′ | N 14°44′ |
| 2 | 348° | 2 | 152°52′ | N 16°12′ |
| 3 | 240° | 3 | 195°57′ | N 17°20′ |
| 4 | 232° | 4 | 193°46′ | N 18°37′ |
| 5 | 69° | 5 | 76°12′ | N 19°54′ |
| 6 | 247° | 6 | 41°59′ | N 21°47′ |
| 7 | 305° | 7 | 334°38′ | N 22°13′ |
| 8 | 155° | 8 | 353°10′ | N 22°31′ |
| 9 | 343° | 9 | 316°32′ | N 22°20′ |
| 10 | 87° | 10 | 35°48′ | N 22°05′ |
| 11 | 290° | 11 | 196°46′ | N 8°06′ |
| 12 | 165° | 12 | 192°58′ | N 39′ |
| 13 | 311° | 13 | 58°25′ | N 5°32′ |
| 14 | 78° | 14 | 28°28′ | S 7°55′ |
| 15 | 126° | 15 | 61°05′ | S 5°03′ |
| 16 | 50° | 16 | 11°49′ | S 29°55′ |
| 17 | 359° | 17 | 344°15′ | N 7°24′ |
| 18 | 30° | 18 | 238°24′ | N 19°29′ |
| 19 | 63° | 19 | 47°51′ | N 45°05′ |
| 20 | 31° | 20 | 86°17′ | N 8°43′ |

| PROBLEM WORK NO. 18 HOUR ANGLE DIAGRAMS | | | | |
|---|---|---|---|---|
| No. | GHA ARIES | SHA | GHA BODY | LHA |
| 1 | | | | 105°02′E |
| 2 | | | 330°41′ | 133°34′E |
| 3 | | | 66°42′ | 106°42′W |
| 4 | | | 122°43′ | 67°17′E |
| 5 | | | 234°15′ | 117°04′W |
| 6 | | | 93°45′ | 160°45′E |
| 7 | | | 28°51′ | 34°21′W |
| 8 | | | 114°34′ | 24°34′W |
| 9 | | | 347°15′ | 150°12′E |
| 10 | | 50°07′ | 310°07′ | 64°53′E |
| 11 | 283°14′ | 259°21′ | 182°35′ | 1°25′W |
| 12 | 27°16′ | 63°00′ | 90°16′ | 19°46′W |
| 13 | 207°56′ | 291°50′ | 139°46′ | 130°09′E |
| 14 | 104°44′ | 113°31′ | 218°15′ | 97°52′W |
| 15 | 210°06′ | 16°22′ | 226°28′ | 113°17′E |
| 16 | 113°45′ | 245°55′ | 359°40′ | 2°35′E |
| 17 | 250°08′ | 77°04′ | 327°12′ | 3°09′E |
| 18 | 32°17′ | 159°27′ | 191°44′ | 96°29′W |



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## CELESTIAL REVIEW TEST NO. 1

3 (a) LHA = 21° West. (b) LHA = 70° East. (c) LHA = 13° West.
(d) LHA = 17° East. (e) LHA = 42° West.

| PROBLEM WORK NO. 19 ALTITUDE CORRECTIONS | | PROBLEM WORK NO. 20 LATITUDE BY POLARIS | | PROBLEM WORK NO. 21 LOCAL ZONE TIME | | |
|---|---|---|---|---|---|---|
| | | | | | ARRIVAL TIME AND DATE | |
| No. | Ho | No. | LATITUDE | No. | GCT | ZONE TIME |
| 1 | 49°11′ | 1 | 32°32′N | 1 | 22:00 May 1 | 12:30 May 1 |
| 2 | 57°49′ | 2 | 38°51′N | 2 | 06:00 May 6 | 20:30 May 5 |
| 3 | 36°17′ | 3 | 37°05′N | 3 | 21:00 May 10 | 09:00 May 11 |
| 4 | 52°41′ | 4 | 39°45′N | 4 | 17:30 May 15 | 03:30 May 16 |
| 5 | 39°01′ | 5 | 30°44′N | 5 | 05:00 May 21 | 16:00 May 21 |
| 6 | 34°22′ | 6 | 37°19′N | 6 | 18:45 May 25 | 08:15 May 25 |
| 7 | 30°48′ | 7 | 43°06′N | 7 | 12:00 May 31 | 05:00 May 31 |
| 8 | 38°06′ | 8 | 23°56′N | 8 | 00:15 May 16 | 13:45 May 15 |
| 9 | 23°17′ | 9 | 31°48′N | 9 | 22:00 May 1 | 10:00 May 2 |
| 10 | 39°41′ | 10 | 25°01′N | 10 | 22:30 May 10 | 09:30 May 11 |
| 11 | 41°14′ | 11 | 34°10′N | 11 | 15:30 May 5 | 01:30 May 6 |
| 12 | 27°27′ | 12 | 26°45′N | 12 | 12:00 May 20 | 23:00 May 20 |
| 13 | 42°38′ | 13 | 43°15′N | 13 | 00:15 May 26 | 12:15 May 26 |
| 14 | 35°22′ | 14 | 29°52′N | 14 | 23:00 May 15 | 12:30 May 15 |
| 15 | 28°51′ | 15 | 44°13′N | 15 | 18:00 May 30 | 08:30 May 30 |
| 16 | 39°16′ | 16 | 37°16′N | 16 | 03:30 May 2 | 20:30 May 1 |
| 17 | 30°32′ | 17 | 28°41′N | 17 | 18:54 May 5 | 09:24 May 5 |
| 18 | 45°07′ | 18 | 44°12′N | 18 | 01:00 May 11 | 18:00 May 10 |
| 19 | 41°58′ | 19 | 33°32′N | | | |
| 20 | 41°27′ | 20 | 38°59′N | | | |

## PROBLEM WORK NO. 22
## LCT — GCT

| No. | LCT TIME | LCT DATE | No. | GCT TIME | GCT DATE |
|---|---|---|---|---|---|
| 1 | 04:30:20 PM | May 1 | 11 | 06:14:40 | May 6 |
| 2 | 05:16:00 AM | May 5 | 12 | 06:21:20 | May 1 |
| 3 | 10:34:00 PM | May 9 | 13 | 06:28:40 | May 10 |
| 4 | 11:39:30 AM | May 16 | 14 | 06:54:00 | May 15 |
| 5 | 08:54:20 AM | May 20 | 15 | 00:50:40 | May 21 |
| 6 | 09:33:20 AM | May 25 | 16 | 00:41:44 | May 26 |
| 7 | 10:43:30 PM | May 29 | 17 | 00:26:40 | May 30 |
| 8 | 00:30:00 AM | May 11 | 18 | 17:16:00 | May 15 |
| 9 | 08:26:10 PM | May 1 | 19 | 10:53:40 | May 6 |
| 10 | 02:26:56 AM | May 16 | 20 | 18:47:16 | May 19 |



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## PROBLEM WORK NO. 23
### ASSUMED POSITION—LHA—DECLINATION

| No. | Assumed Position Lat. | Assumed Position Long. | LHA | Dec. |
|---|---|---|---|---|
| 1 | 34°N | 110°48′E | 92°W | N 19°29′ |
| 2 | 23°S | 172°20′W | 18°E | N 16°12′ |
| 3 | 14°N | 117°28′W | 57°E | N 22°19′ |
| 4 | 22°N | 178°11′E | 34°W | N 18°37′ |
| 5 | 11°S | 124°04′E | 77°W | S 60°36′ |
| 6 | 15°N | 117°26′E | 80°W | N 5°22′ |
| 7 | 33°N | 168°31′W | 20°W | N 14°45′ |
| 8 | 18°S | 104°51′E | 48°W | N 25°17′ |
| 9 | 15°S | 167°46′E | 64°E | S 26°22′ |
| 10 | 32°S | 114°57′W | 78°E | N 1°25′ |
| 11 | 19°N | 127°21′W | 42°E | S 10°52′ |
| 12 | 7°S | 91°58′W | 89°W | N 16°24′ |
| 13 | 20°N | 116°16′W | 98°W | N 7°24′ |
| 14 | 4°N | 152°26′W | 40°E | S 8°16′ |
| 15 | 17°S | 86°32′E | 63°E | S 52°40′ |
| 16 | 31°S | 178°01′W | 37°W | N 18°37′ |
| 17 | 20°N | 116°53′W | 82°W | N 6°18′ |
| 18 | 18°S | 172°39′E | 17°E | N 21°45′ |
| 19 | 14°S | 178°46′W | 22°E | S 60°36′ |
| 20 | 24°N | 162°27′W | 54°W | N 5°22′ |

## PROBLEM WORK NO. 24
### ALTITUDE AND AZIMUTH (H.O. 214)

| No. | Hc | AZIMUTH |
|---|---|---|
| 1 | 28°18.2′ | N 91.3°W |
| 2 | 46°45.9′ | N 93.8°E |
| 3 | 14°13.5′ | N 117.9°E |
| 4 | 56°23.9′ | N 107.2°W |
| 5 | 49°17.9′ | N 105.1°W |
| 6 | 62°47.9′ | S 34.8°W |
| 7 | 37°40.8′ | N 104.2°E |
| 8 | 17°57.8′ | N 142.8°W |
| 9 | 60°38.7′ | N 105.9°E |
| 10 | 44°02.0′ | N 121.8°W |
| 11 | 64°56.2′ | N 45.8°E |
| 12 | 55°06.4′ | N 55.8°W |
| 13 | 73°36.6′ | S 88.7°E |
| 14 | 20°15.8′ | S 152.8°W |
| 15 | 40°33.0′ | N 116.5°E |
| 16 | 32°06.8′ | S 133.3°E |
| 17 | 45°34.0′ | S 114.5°W |
| 18 | 35°45.5′ | N 147.5°E |
| 19 | 24°18.1′ | N 129.3°W |
| 20 | 66°18.1′ | N 66.3°E |

## PROBLEM WORK NO. 25 AND NO. 26
### ASSUMED POSITION—INTERCEPT—AZIMUTH (PLOT ON CHART)

| No. | Assumed Position Lat. | Assumed Position Long. | INTERCEPT | AZIMUTH |
|---|---|---|---|---|
| 1 | 35°S | 155°45′E | 18.6′ toward | S 70.7°E |
| 2 | 35°S | 153°23′E | 0.6′ away | S 11.9°W |
| 3 | 35°S | 153°49′E | 8.6′ away | S 131.1°E |
| 4 | 30°N | 160°26′W | 28.1′ away | N 85.1°W |
| 5 | 30°N | 158°36′W | 19.9′ toward | N 96.0°E |
| 6 | 30°N | 161°31′W | 39.1′ away | N 163.0°E |
| 7 | 39°N | 152°25′E | 7.2′ away | N 116.7°W |
| 8 | 39°N | 151°14′E | 0.0 | 0.0° |
| 9 | 39°N | 151°04′E | 14.2′ toward | N 164.1°W |
| 10 | 33°N | 135°30′W | 21.0′ toward | N 81.6°E |
| 11 | 33°N | 136°01′W | 3.8′ toward | N 140.4°W |
| 12 | 33°N | 136°03′W | 22.0′ away | N 117.4°W |
| 13 | 36°S | 145°00′W | 7.2′ away | S 141.5°W |
| 14 | 36°S | 146°06′W | 9.0′ toward | S 177.7°W |
| 15 | 36°S | 146°45′W | 18.7′ toward | S 144.0°E |
| 16 | 32°S | 155°36′E | 14.6′ away | S 99.2°E |
| 17 | 32°S | 156°59′E | 2.2′ away | S 127.2°W |
| 18 | 32°S | 156°18′E | 14.8′ away | S 172.1°E |
| 19 | 38°S | 133°47′W | 4.1′ away | S 147.2°W |
| 20 | 38°S | 135°20′W | 7.8′ toward | S 173.6°W |

## PROBLEM WORK NO. 27
### ADVANCING SINGLE LINES OF POSITION

| No. | Az | Intercept | N. M. Advance |
|---|---|---|---|
| 1 | N 104°E | 28′ away | 15 |
| 2 | S 146°W | 46′ toward | 33 |
| 3 | S 138°W | 9′ toward | 133 |
| 4 | N 123°W | 20′ toward | 82 |
| 5 | S 172°E | 7′ toward | 53 |
| 6 | S 156°E | 28′ toward | 25 |
| 7 | N 109°E | 28′ toward | 6 |
| 8 | S 105°E | 34′ away | 18 |
| 9 | N 125°W | 40′ away | 40 |
| 10 | S 140°W | 37′ toward | 6 |
| 11 | N 147°E | 44′ away | 51 |
| 12 | S 116°W | 47′ away | 7 |
| 13 | N 87°W | 23′ away | 14 |
| 14 | N 88°W | 31′ away | 60 |
| 15 | N 123°E | 7′ toward | 24 |
| 16 | Latitude 35°42′N | | 6 |
| 17 | N 108°E | 23′ away | 17 |
| 18 | N 76°E | 20′ toward | 11 |
| 19 | S 121°W | 27′ toward | 9 |
| 20 | N 33°W | 10′ toward | 29 |



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## CELESTIAL REVIEW TEST NO. 2

3 (a) LHA Sun = 160° West. (b) LHA Star = 40° East. GHA Star = 240°.

4 (a) GCT = 02:31, January 3rd. (b) LCT = 6:08 AM July 16th.

5 (a) LZT = 6:30 PM August 3rd. (b) LZT = 4:30 PM January 6th.

6 GHA Sun = 350°49′, Declination = 14°53′N.

GHA Moon = 23°46′, Declination = 1°35′S.

GHA$_*$ Sirius = 287°58′, Declination = 16°38′S.

7 $H_O$ Sun = 30°13′. $H_O$ Venus = 60°09′. $H_O$ Altair = 20°04′. $H_O$ Moon = 29°15′.

8 Latitude = 32°48′ North.

9 Altitude Intercept = 7.1 away, Azimuth = N 158°E.

## PROBLEM WORK NO. 28
### THREE STAR FIXES

| No. | FIX Lat. | FIX Long. |
|---|---|---|
| 1 | 31°57′N | 9°19′W |
| 2 | 32°08′S | 136°33′E |
| 3 | 35°08′N | 16°59′E |
| 4 | 31°31′N | 179°40′W |
| 5 | 39°36′N | 175°27′W |
| 6 | 32°38′N | 119°25′W |
| 7 | 36°08′N | 125°33′E |
| 8 | 31°33′N | 139°25′W |

## PROBLEM WORK NO. 29
### TRACK AND GROUND SPEED BETWEEN FIXES

| No. | POSITION Lat. | POSITION Long. | Track | Ground Speed | Drift | Wind | True Heading |
|---|---|---|---|---|---|---|---|
| 1 | | | | 177 | | | |
| 2 | 34°48′N | 127°15′W | 231° | 185 | 11°L | 340°/34 | 242° |
| 3 | 33°25′N | 130°07′W | 240° | 200 | 18°L | 358°/63 | 258° |
| 4 | 33°27′N | 133°41′W | 271° | 213 | 4°R | 108°/38 | 267° |
| 5 | 31°31′N | 136°54′W | 235° | 160 | 7°R | 181°/26 | 228° |

## PROBLEM WORK NO. 30
### STAR IDENTIFICATION BY H. O. 214

| No. | STAR | No. | STAR |
|---|---|---|---|
| 1 | Vega | 11 | Rasalague |
| 2 | Adhara | 12 | Kaus-Australis |
| 3 | Spica | 13 | Canopus |
| 4 | Altair | 14 | Denebola |
| 5 | Regulus | 15 | Alioth |
| 6 | Miaplacidus | 16 | Dschubba |
| 7 | Alphecca | 17 | Shaula |
| 8 | Antares | 18 | Deneb |
| 9 | Nunki | 19 | Alpheratz |
| 10 | Sabik | 20 | Deneb-Kaitos |

## PROBLEM WORK NO. 31
### LATITUDE BY MERIDIAN ALTITUDE

| No. | LATITUDE | No. | LATITUDE |
|---|---|---|---|
| 1 | 25°58′N | 11 | 32°41′N |
| 2 | 3°10′N | 12 | 23°39′N |
| 3 | 45°57′N | 13 | 22°49′N |
| 4 | 13°21′S | 14 | 32°43′N |
| 5 | 24°00′S | 15 | 29°19′N |
| 6 | 43°56′N | 16 | 12°35′S |
| 7 | 29°53′N | 17 | 41°52′N |
| 8 | 32°41′N | 18 | 26°20′S |
| 9 | 5°02′S | 19 | 6°13′S |
| 10 | 35°25′N | 20 | 0°19′S |



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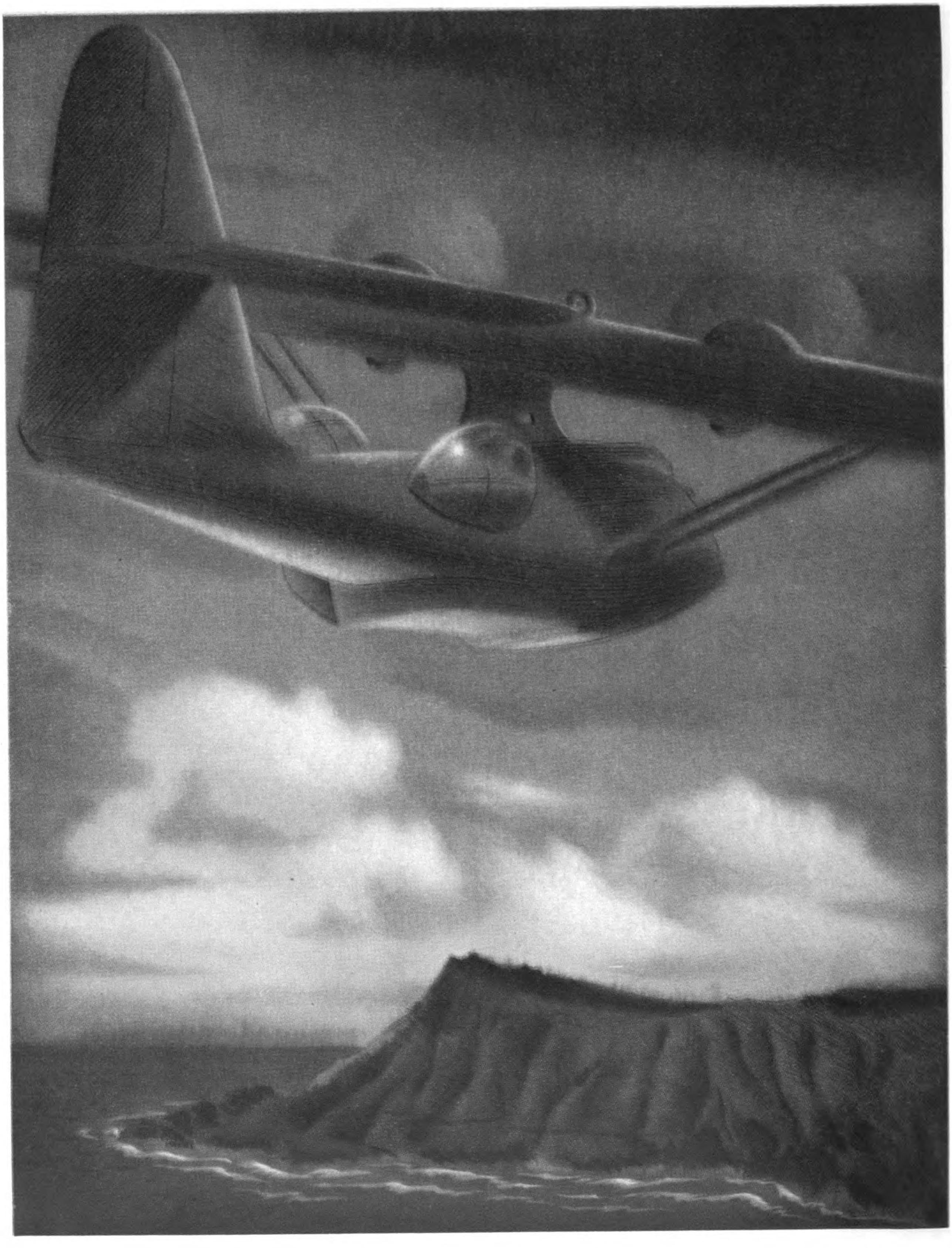

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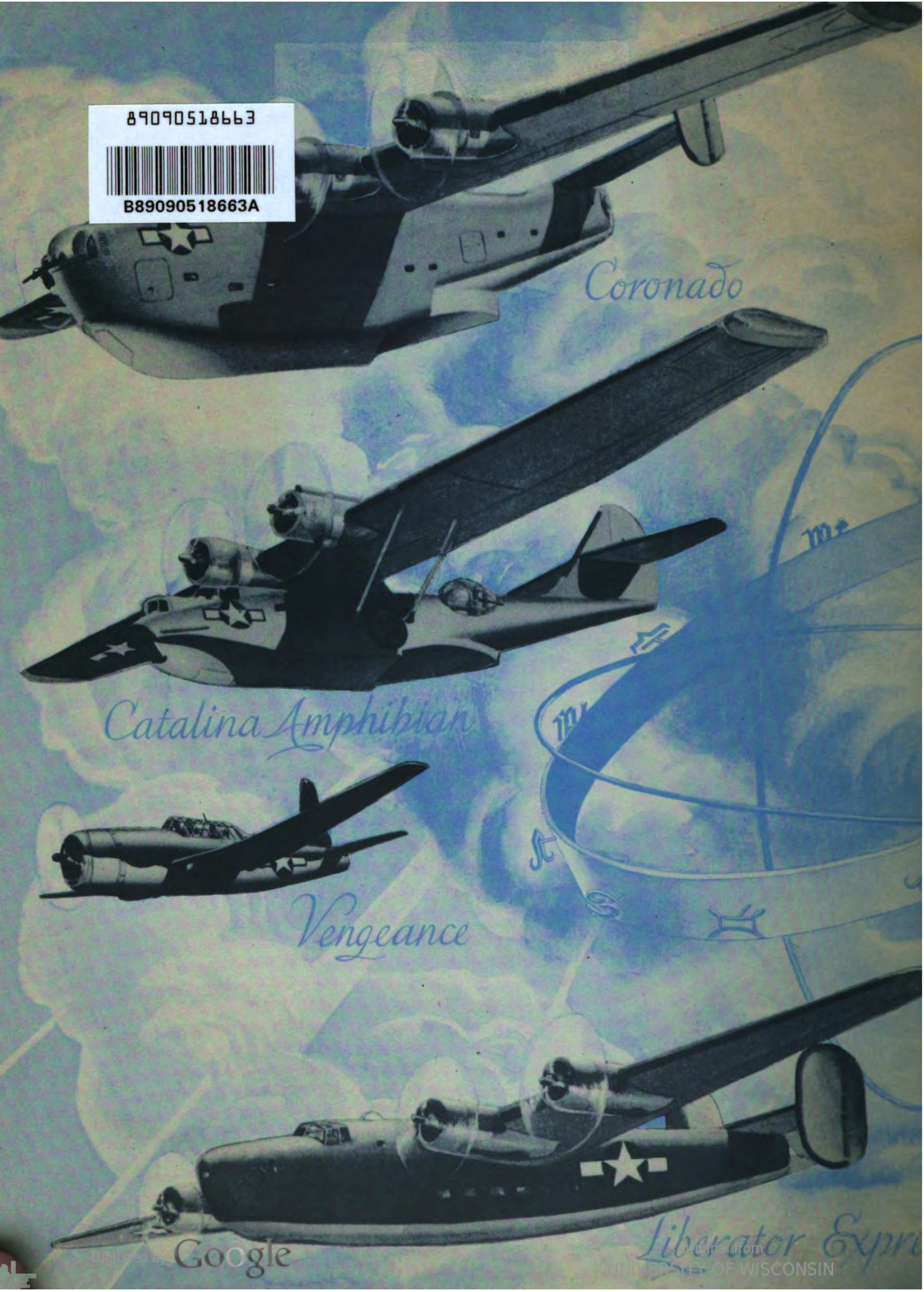


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